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Influence of the Form Of Steam Nozzles on the Impulsive Effect of the Jet

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EXPERIMENTS ON THE INFLUENCE OF THE FORM OF STEAM NOZZLES ON THE IMPULSIVE EFFECT OF THE JET

BY

CHARLES FRED DOSCH

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
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Experiments on the Influence of the Form of Steam Nozzles on the Impulsive Effect of the Jet.

Chapter I.

Historical Outline of the Development of the Laws of the Flow of Elastic Fluids.

Since the advent of the steam turbine the phenomena of steam flow, steam velocity, and steam impact, have received considerable attention, both from the theoretical and the experimental side. The theory is, as yet, however, far from complete and satisfactory, and the experimental work is merely fragmentary. The theory of steam flow depends primarily on the theory of the flow of elastic fluids, and a short historical sketch will be of aid in appreciating the peculiar difficulties and apparent contradictions met with in this subject.

Shortly after Galileo established the laws of falling bodies, further experiment showed that water and other inelastic fluids followed the same law. Proven that the velocity of water flowing through a properly shaped orifice was equal to the velocity which a body would acquire in falling a distance equal to the head, it followed that the velocity of efflux varied as the

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square root of the head. This law was applied to elastic fluids, such as air, and crude experiments were made on a bladder first filled with air, and then with water. Under the same pressure it if was found that it required 25 times as long to empty the bladder when filled with water as when filled with air; consequently the velocity of flow of air was considered as 25 times that of ~~a~~water.

In a quaint old, of paper read by a certain Dr. Papin before the Royal Society in 1686, the following is stated as the general law deduced from theory and experiment: "Of different liquors flowing from an orifice bearing the same pressure, those lighter in specie must acquire the greater swiftness, and their velocities are to one another as the roots of the specific gravities of the said liquors. As much as the specific gravity of water doth exceed the square root of the specific gravity of air, so much in proportion will the velocity of air exceed the velocity of water." This law was accepted for 115 years, and it was not until late in the nineteenth century that further experiments were made.

In 1843 St. Venant and Wantzel made the first real advance, and in their report give the first real intimation of one of

the well known results of modern experiment. They make two important statements:

(1). When a pressure which acts in an opposite direction to the flow of the gas descends below three fifths of the pressure which causes the flow, the efflux instead of increasing, diminishes.

(2). ~~a~~ gas cannot flow into a vacuum whatever be its pressure.

These two conclusions so apparently opposed to all reason were too much for the experimenters, and after a second series of experiments St. Venant says, "Our experiments have proved that those singular results have no more reality than they had probability."

As late as 1846 Prof. Graham of the Royal Society announced that his experiments left no doubt as to the truth of the general law that different gases pass through minute apertures in times which are inversely as the square roots of their specific gravities. Experimenting and investigating along the same line in 1847 Mr. William Fronde developed a theory of flow by which he proved that elastic fluids under pressure cannot flow into a vacuum. His method of experiment was similar to that of St. Venant, Wangel and Graham.

From 1854 to 1862 Prof. Thomas and Dr. Joule made as series of experiments on the flow of air to determine the velocity through small orifices in thin plates. In Dr. Joule's report he gives a hint of one fact which has since proved of considerable importance He says, "I have not been able to detect any effect due to vibration of the issuing stream..... there can be no doubt vibration constituting sound will be able to travel back through the air rushing through the orifice if its velocity be not greater than 1090 feet per second. I have failed, however, to discover any sensible influence from this cause on the velocity of efflux.

Robert D. Napier, in 1866, was the first to state what we know now to be the actual conditions under which steam or a gas flows from a higher to a lower pressure. His important conclusion, and the one which we know to be approximately true is, as he states it; "Steam at a pressure of two or more atmospheres will rush from a boiler through an orifice or short tube into the air, exactly at the same rate as it will into a vacuum, or into any pressure less than that of the atmosphere; and generally a gas of any given pressure will rush from one vessel into

into another containing a gas of half the pressure at the same rate as if there were a perfect vacuum in the recipient vessel, or any intermediate pressure between a vacuum and half the pressure in the cistern, both pressures being taken from zero."

This conclusion, it is seen, had been once reached by St. Venant and Wantzel twenty years before, and afterwards rejected by them as absolutely impossible. At this time Napier's experiments provoked heated arguments, but nevertheless the truth of his deductions was soon established as a scientific fact, Prof. Rankine being one of the first to refute argument brought against it, and one of the ardent supporters of the new theory.

The German scientists Zeuner, Fliegner and Grashof have since developed the theory and experiments more fully. In conclusion it may be said that at the present time the laws of the flow of gases through orifices in thin plates are known, and that the theory is supported by experiment.

Briefly stated the law of the flow is as follows: "When a gas flows through an orifice from a reservoir in which there exists a tower pressure P_2, the quantity of

gas passing through the orifice continuously increases as P_2 decreases until P_2 reaches the value .527 P_1, for air, and .58 P_1 for steam. Any decrease of P_2 below this point has no effect on the quantity of gas flowing through an orifice in a given time. In other words when the maximum flow occurs $\frac{P_2}{P_1} = .527$ for a gas and .58 for steam. As to the laws of flow in tubes of varying cross section, and the phenomena taking place in the tube itself, much uncertainty exists, and it is along this line that recent experimenters and scientists are now working.

Chapter II.

Theory.

The impact exerted by the steam issuing from a nozzle depends primarily upon two factors i.e., the mass and the velocity. There is a maximum quantity of flow which can flow from a given orifice from a fixed initial pressure, provided that the back pressure is less than .58 of the initial pressure. According to this theory, so since the back pressure maintained was atmospheric or 14.7 lbs. per square inch, the maximum flow was obtained in the experiments as here performed for all initial pressures above and including 30 lbs. per square inch. Since this applies to any orifice or short tube, it follows that the only factor which could change the impact for pressures above 30 lbs. per square inch, due to shape of nozzle etc., was that involving the velocity.

The velocity of the steam at the critical section of a nozzle is given by the following formula:

$$V = \sqrt{\frac{2gkP_1V_1}{K+1}}$$

where $K = 1.33$ for steam

P_1 = initial pressure of steam.

V_1 = " volume " ".

g = gravity = 32.2.

From this the maximum mass which can flow from the nozzle is

$$M = F\sqrt{\frac{2gKP_1V_1}{K+1}}$$

where F = area at critical section.

The critical section for a straight nozzle is at the mouth. For a diverging nozzle it is theoretically at the smallest section, but actually a short distance beyond it, depending upon the coefficient of friction and the value of K.

Chapter III.

Description of Apparatus.

The general arrangement of the apparatus is shown in figure 1 on page 12. The receiver b consists of a 12" length of 6" wrought iron pipe, having a cap on each end, the whole being supported by the three legs marked l. Steam enters the receiver through the supply pipe a. This is of 1" diameter, and extends into the receiver for 8", the end being capped, while perforations along its length admit the steam into the receiver. The nozzle c screws into the bottom of the receiver as ~~soo~~ shown. The steam issuing from this nozzle strikes the plate d, and the impact is measured by the increased pressure or weight on the platform scales marked e. The impact plate consists of the adjustable plate d, and the base g. The adjusting screws h enable the plate d to be placed perpendicular to the nozzle axis. The steam gage f is placed as shown, it being attached to a $\frac{1}{4}$" pipe extending into the receiver.

The nozzles used were three in number shown in figure 3 on page 13. The hole at

the small ends, was ¼" in diameter. In constructing these nozzles all care was taken to get the tapers and desired length as exact as possible, as was also the case with the entrance opening.

The method of piping is shown on page 11, and on page 13 will be found a sketch of the receiver.

METHOD OF PIPING.

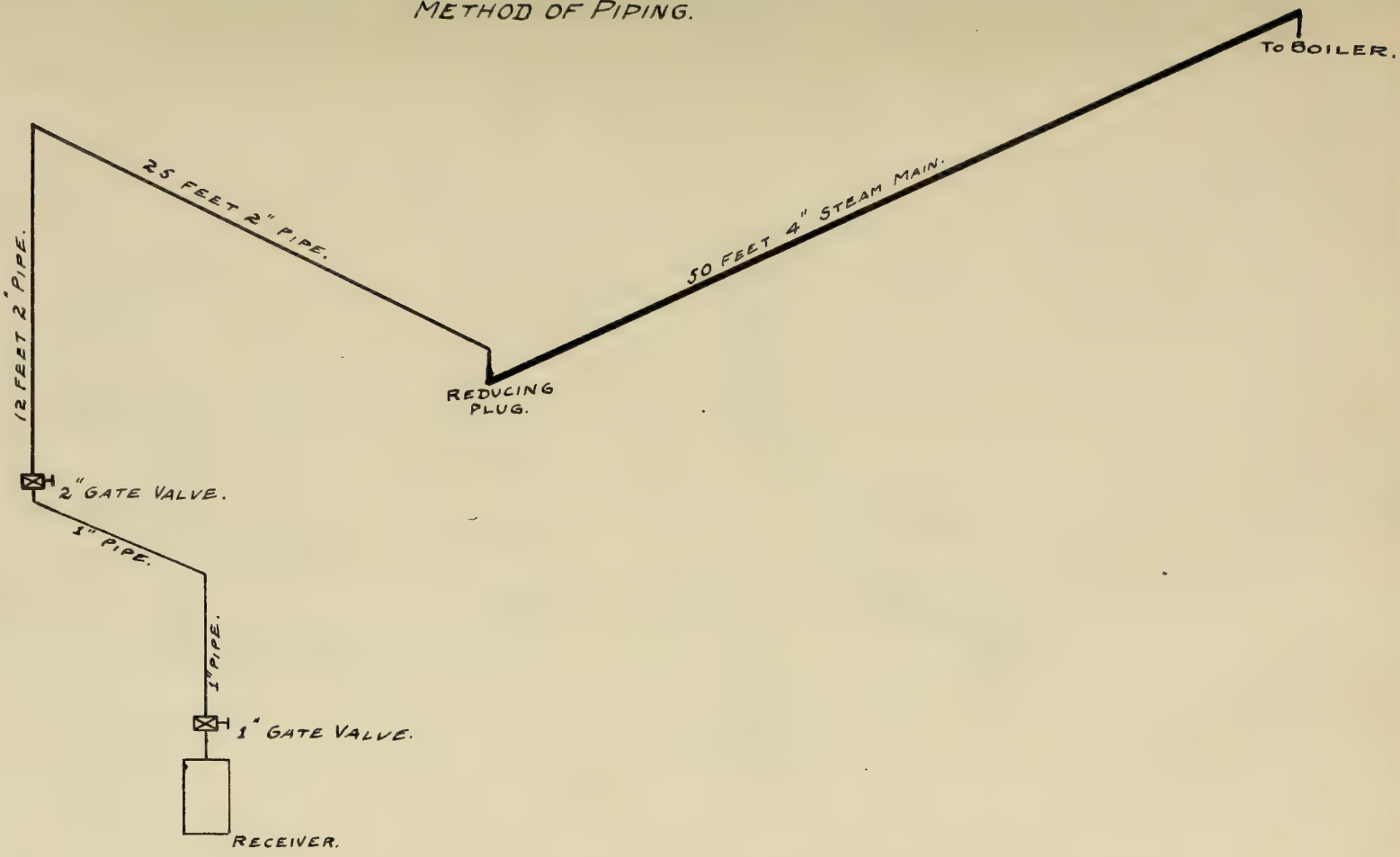
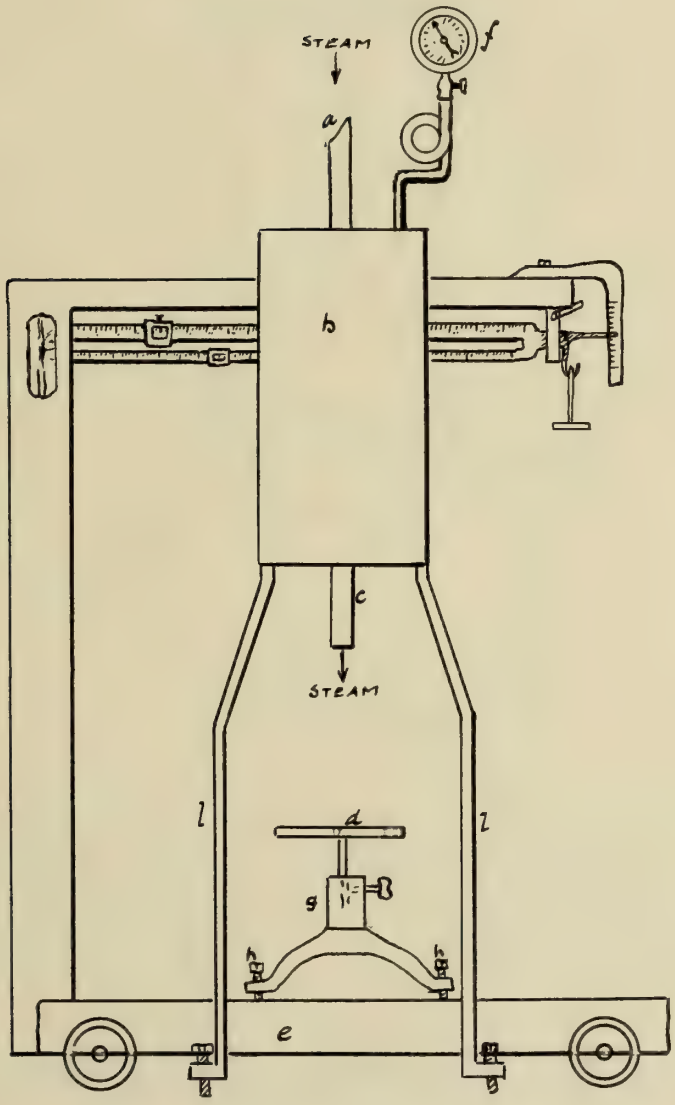
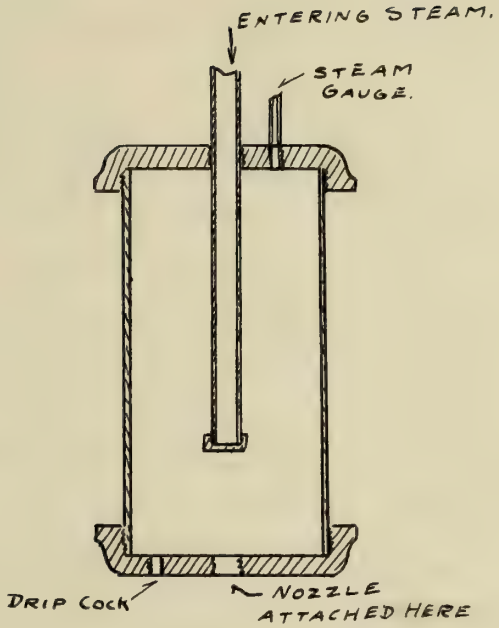


FIGURE 1.



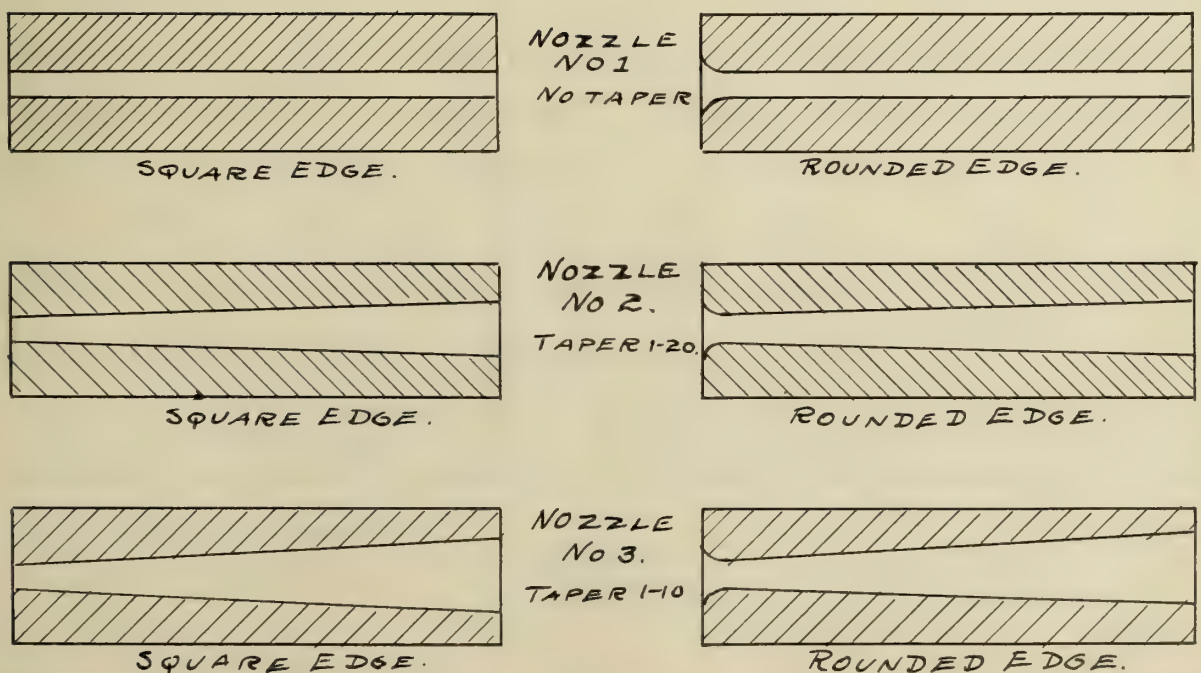
DIAGRAMATICAL SKETCH OF APPARATUS.



RECEIVER.

FIGURE 3.

NOZZLES



Chapter IV.

Method of Conducting Experiments.

The apparatus was first placed in position as shown in figure 1 on page 12. The plate d was adjusted at the proper distance from the nozzle, and also levelled up so that it was perpendicular to the nozzle axis. The weight of the plate and its base was then balanced so that the scale reading was zero. Steam was then turned on, and by means of a throttle valve the pressure was regulated to that pressure wanted in the receiver. This pressure was then varied by ten pound drops, from 120 to 10 lbs. per square inch, and the corresponding scale readings noted. This procedure was repeated for different positions of the plate, and with the various nozzles with different lengths and tapers.

The inner edge of each nozzle was then rounded, and the results of this operation were noted.

Two readings of each operation were taken and the mean used for points on the various curves.

Nozzle No 1, (no taper - square inner edge).
Length of Nozzle = 5."

Nozzle $\frac{3}{8}$" from plate.				Nozzle 1" from plate.			
Press.	Impact.	Impact.	Average Impact.	Press.	Impact.	Impact.	Average Impact.
120	-----	-----	-----	120	-----	-----	-----
110	5.23	-----	5.23	110	5.42	5.48	5.45
100	4.68	4.84	4.74	100	4.98	5.00	4.99
90	4.26	4.31	4.28	90	4.44	4.46	4.45
80	3.70	3.74	3.72	80	3.85	3.96	3.90
70	3.24	3.24	3.24	70	3.39	3.46	3.42
60	2.72	2.62	2.67	60	2.87	2.92	2.90
50	2.16	2.08	2.12	50	2.31	2.36	2.34
40	1.66	1.60	1.63	40	1.87	1.96	1.92
30	1.17	1.15	1.16	30	1.35	1.38	1.36
20	.73	.74	.73	20	.77	.83	.80
10	.35	.35	.35	10	.34	.35	.34

Nozzle 2" from plate.				Nozzle $2\frac{1}{2}$" from plate.			
Press.	Impact.	Impact.	Average Impact.	Press.	Impact.	Impact.	Average Impact.
120	-----	-------	-----	120	-----	------	-----
110	5.54	5.59	5.56	110	5.62	5.60	5.61
100	5.00	5.06	5.03	100	5.08	5.07	5.08
90	4.52	4.60	4.56	90	4.58	4.61	5.60
80	3.93	4.01	3.97	80	4.05	4.05	4.05
70	3.48	3.46	3.47	70	3.48	3.48	3.48
60	2.84	2.93	2.88	60	2.89	2.90	2.90
50	2.46	2.46	2.46	50	2.44	2.41	2.42
40	1.93	1.99	1.96	40	1.90	1.92	1.91
30	1.32	1.40	1.36	30	1.38	1.36	1.37
20	.77	.80	.78	20	.82	.83	.82
10	.29	.33	.31	10	.34	.36	.35

NOZZLE NO 1. (NO TAPER - SQUARE INNER EDGE).
LENGTH OF NOZZLE = 5."

NOZZLE 3" FROM PLATE.				NOZZLE 4" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	------	------	------	120	-------	------	------
110	5.56	5.48	5.52	110	5.60	5.62	5.61
100	5.01	5.03	5.02	100	5.07	5.14	5.11
90	4.46	4.54	4.50	90	4.62	4.62	4.62
80	3.92	3.92	3.92	80	4.08	4.14	4.11
70	3.32	3.52	3.42	70	3.46	3.54	3.50
60	2.93	2.96	2.94	60	2.94	3.00	2.96
50	2.29	2.31	2.30	50	2.54	2.56	2.55
40	1.87	1.75	1.83	40	2.02	2.04	2.03
30	1.30	1.32	1.31	30	1.47	1.50	1.48
20	.65	.73	.69	20	.97	.94	.96
10	.22	.25	.23	10	.35	.39	.37

NOZZLE 5" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	------	------	-------
110	5.51	5.57	5.53
100	5.00	5.02	5.01
90	4.55	4.60	4.58
80	4.05	4.10	4.07
70	3.50	3.50	3.50
60	3.04	3.08	3.06
50	2.45	2.52	2.49
40	2.06	2.10	2.08
30	1.42	1.49	1.46
20	.80	.89	.84
10	.38	.46	.41

NOZZLE NO 1 (ROUNDED INNER EDGE, NO TAPER).
LENGTH OF NOZZLE = 5"

NOZZLE $\frac{1}{4}$" FROM PLATE.				NOZZLE 1" FROM PLATE.			
PRESS.	IMPACT	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.16	7.16	7.16	120	7.59	7.58	7.58
110	6.60	6.70	6.65	110	7.16	7.04	7.10
100	6.04	6.11	6.07	100	6.52	6.34	6.42
90	5.44	5.57	5.48	90	5.90	5.80	5.85
80	4.92	4.96	4.94	80	5.14	5.20	5.17
70	4.26	4.37	4.31	70	4.65	4.63	4.64
60	3.80	3.72	3.76	60	4.06	4.00	4.03
50	3.14	3.22	3.18	50	3.48	3.48	3.48
40	2.75	2.78	2.76	40	2.92	2.88	2.90
30	1.88	1.96	1.92	30	2.24	2.22	2.23
20	1.32	1.40	1.36	20	1.62	1.64	1.63
10	.94	.94	.94	10	1.04	1.00	1.02

NOZZLE 2" FROM PLATE.				NOZZLE $2\frac{1}{2}$" FROM PLATE.			
PRESS.	IMPACT.	IMPACT	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.70	7.76	7.73	120	7.17	7.18	7.17
110	7.18	7.16	7.17	110	6.62	6.62	6.62
100	6.51	6.58	6.54	100	6.04	6.06	6.05
90	5.97	5.90	5.93	90	5.42	5.36	5.39
80	5.36	5.20	5.28	80	4.82	4.84	4.83
70	4.76	4.75	4.75	70	4.20	4.20	4.20
60	4.14	4.12	4.13	60	3.52	3.54	3.53
50	3.52	3.44	3.48	50	3.02	2.92	2.97
40	3.02	2.96	2.98	40	2.40	2.48	2.44
30	2.28	2.32	2.30	30	1.76	1.74	1.75
20	1.56	1.68	1.62	20	1.08	1.00	1.04
10	.99	1.09	1.04	10	.47	.42	.44

NOZZLE NO 1, (NO TAPER, ROUNDED INNER EDGE.)
LENGTH OF NOZZLE = 5."

NOZZLE 3" FROM PLATE.				NOZZLE 4" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.22	7.14	7.18	120	6.97	6.96	6.96
110	6.62	6.54	6.58	110	6.44	6.42	6.43
100	6.02	6.00	6.01	100	5.74	5.81	5.77
90	5.38	5.30	5.34	90	5.08	5.17	5.12
80	4.72	4.74	4.73	80	4.56	4.54	4.55
70	4.06	4.12	4.09	70	3.96	3.96	3.96
60	3.56	3.62	3.59	60	3.37	3.34	3.35
50	2.90	2.94	2.92	50	2.76	2.72	2.74
40	2.42	2.40	2.41	40	2.27	2.24	2.25
30	1.70	1.66	1.68	30	1.65	1.55	1.55
20	1.04	1.10	1.07	20	.88	.92	.90
10	.37	.37	.37	10	.33	.27	.30

NOZZLE 5" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	6.89	6.84	6.86
110	6.40	6.38	6.39
100	5.76	5.76	5.76
90	5.07	5.05	5.06
80	4.55	4.55	4.55
70	3.87	3.98	3.92
60	3.34	3.38	3.36
50	2.70	2.70	2.70
40	2.26	2.23	2.24
30	1.51	1.57	1.54
20	.87	.89	.88
10	.20	.24	.22

NOZZLE NO 1 (NO TAPER, ROUNDED INNER EDGE.)
LENGTH OF NOZZLE = 3½".

NOZZLE ¼" FROM PLATE.				NOZZLE 1" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.06	6.94	7.02	120	7.32	7.20	7.26
110	6.40	6.40	6.40	110	6.72	6.70	6.71
100	5.84	5.76	5.80	100	6.10	6.08	6.09
90	5.18	5.16	5.17	90	5.52	5.40	5.46
80	4.66	4.64	4.65	80	4.82	4.82	4.82
70	3.96	4.04	4.00	70	4.28	4.26	4.27
60	3.34	3.40	3.37	60	3.56	3.66	3.61
50	2.80	2.82	2.81	50	2.96	2.94	2.95
40	2.32	2.32	2.32	40	2.52	2.44	2.48
30	1.67	1.70	1.68	30	1.98	1.80	1.89
20	1.02	1.10	1.06	20	1.28	1.18	1.23
10	.56	.52	.53	10	.66	.60	.63

NOZZLE 2" FROM PLATE.				NOZZLE 2½" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.68	7.50	7.59	120	7.58	7.60	7.59
110	7.12	6.98	7.05	110	7.02	7.10	7.06
100	6.56	6.42	6.49	100	6.48	6.54	6.51
90	5.88	5.70	5.79	90	5.82	5.88	5.85
80	5.26	5.10	5.18	80	5.16	5.10	5.13
70	4.42	4.52	4.47	70	4.64	4.64	4.64
60	3.86	3.90	3.88	60	3.94	3.96	3.95
50	3.24	3.32	3.28	50	3.30	3.36	3.33
40	2.70	2.80	2.75	40	2.88	2.82	2.85
30	2.09	2.14	2.11	30	2.20	2.18	2.19
20	1.46	1.40	1.43	20	1.56	1.56	1.56
10	.80	.70	.75	10	.90	.78	.84

NOZZLE No 1. (NO TAPER, ROUNDED INNER EDGE.)
LENGTH OF NOZZLE = 3 1/2".

NOZZLE 3" FROM PLATE.				NOZZLE 4" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.28	7.38	7.33	120	7.18	7.28	7.23
110	6.74	6.82	6.78	110	6.68	6.82	6.75
100	6.04	6.18	6.11	100	6.04	6.18	6.11
90	5.44	5.56	5.49	90	5.41	5.58	5.49
80	4.82	4.96	4.89	80	4.86	4.96	4.91
70	4.24	4.30	4.27	70	4.28	4.30	4.29
60	3.52	3.70	3.61	60	3.60	3.76	3.68
50	2.94	3.04	2.99	50	3.10	3.16	3.13
40	2.46	2.52	2.49	40	2.60	2.56	2.58
30	1.82	1.84	1.83	30	1.96	1.98	1.97
20	1.14	1.12	1.13	20	1.18	1.24	1.21
10	.46	.48	.47	10	.56	.58	.57

NOZZLE 5" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.10	7.14	7.12
110	6.58	6.58	6.58
100	5.98	5.94	5.96
90	5.38	5.42	5.40
80	4.92	4.92	4.92
70	4.38	4.22	4.26
60	3.70	3.74	3.72
50	3.18	3.16	3.17
40	2.54	2.62	2.58
30	1.90	1.92	1.91
20	1.28	1.28	1.28
10	.64	.68	.66

SUMMARY.
NOZZLE NO 1, NO TAPER.

IMPACT.

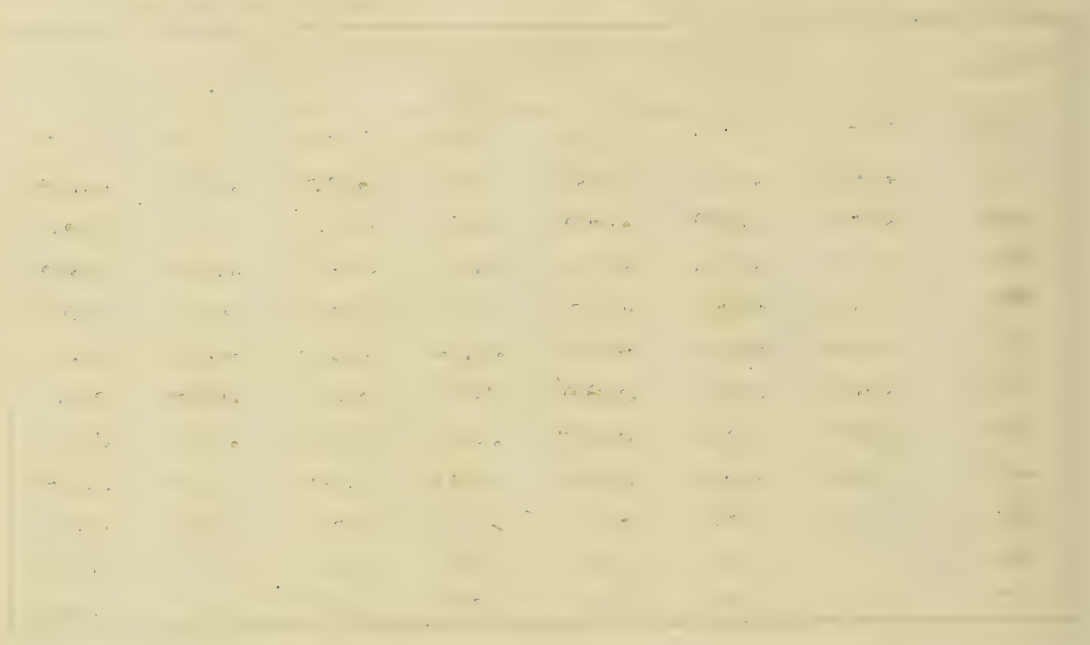
LENGTH OF NOZZLE = 5." SQUARE INNER EDGE.

PRESS.	DISTANCE OF NOZZLE FROM PLATE.						
	3/8"	1"	2"	2 1/2"	3"	4"	5"
120	-----	------	-----	------	-----	-----	----
110	5.23	5.45	5.56	5.61	5.52	5.62	5.53
100	4.74	4.99	5.03	5.08	5.02	5.11	5.01
90	4.28	4.45	4.56	4.60	4.50	4.62	4.58
80	3.72	3.90	3.97	4.05	3.92	4.11	4.07
70	3.24	3.42	3.47	3.48	3.42	3.50	3.50
60	2.67	2.90	2.88	2.90	2.94	2.69	3.06
50	2.12	2.34	2.46	2.42	2.30	2.55	2.49
40	1.63	1.92	1.96	1.91	1.83	2.03	2.08
30	1.16	1.36	1.36	1.37	1.31	1.48	1.46
20	.73	.80	.78	.82	.69	.96	.84
10	.35	.34	.31	.35	.23	.37	.41

IMPACT.

LENGTH OF NOZZLE = 5." ROUNDED INNER EDGE.

PRESS.	DISTANCE OF NOZZLE FROM PLATE.						
	1/4"	1"	2"	2 1/2"	3"	4"	5"
120	7.16	7.58	7.73	7.17	7.18	6.96	6.86
110	6.65	7.10	7.17	6.62	6.58	6.43	6.39
100	6.06	6.42	6.54	6.05	6.01	5.77	5.76
90	5.48	5.85	5.93	5.39	5.34	5.12	5.06
80	4.94	5.17	5.28	4.83	4.73	4.55	4.55
70	4.31	4.64	4.75	4.20	4.09	3.96	3.92
60	3.76	4.03	4.13	3.53	3.59	3.35	3.36
50	3.18	3.84	3.48	2.97	2.92	2.74	2.70
40	2.76	2.90	2.98	2.44	2.41	2.25	2.24
30	1.92	2.23	2.30	1.75	1.68	1.55	1.54
20	1.36	1.63	1.62	1.04	1.07	.90	.88
10	.94	1.02	1.04	.44	.37	.30	.22



SUMMARY.

NOZZLE NO 1; NO TAPER.

IMPACT.

LENGTH OF NOZZLE = $3\frac{1}{2}$". ROUNDED INNER EDGE.

PRESS.	DISTANCE OF NOZZLE FROM PLATE.						
	¼".	1".	2".	2½".	3".	4".	5".
120	7.02	7.26	7.59	7.59	7.33	7.23	7.12
110	6.40	6.71	7.05	7.06	6.38	6.75	6.58
100	5.80	6.09	6.49	6.51	6.11	6.11	5.96
90	5.17	5.46	5.79	5.85	5.49	5.49	5.40
80	4.65	4.82	5.18	5.13	4.89	4.91	4.92
70	4.00	4.27	4.47	4.64	4.27	4.29	4.26
60	3.37	3.61	3.88	3.95	3.61	3.68	3.72
50	2.81	2.95	3.28	3.33	2.99	3.13	3.17
40	2.32	2.48	2.75	2.85	2.49	2.58	2.58
30	1.68	1.89	2.11	2.19	1.83	1.97	1.91
20	1.06	1.23	1.43	1.56	1.13	1.21	1.28
10	.53	.63	.75	.84	.47	.57	.66

NOZZLE No 2 (TAPER 1-20, SQUARE INNER EDGE).
LENGTH OF NOZZLE = 5."

NOZZLE ¼" FROM PLATE.				NOZZLE 1" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	------	5.07	5.07	120	5.38	5.38	5.38
110	4.54	4.71	4.63	110	4.84	4.90	4.87
100	4.04	4.10	4.07	100	4.24	4.30	4.27
90	3.47	3.54	3.49	90	3.71	3.73	3.72
80	2.90	2.89	2.89	80	3.07	3.10	3.08
70	2.29	2.38	2.33	70	2.54	2.56	2.55
60	1.78	1.89	1.83	60	1.96	2.00	1.98
50	1.27	1.40	1.33	50	1.52	1.47	1.50
40	.95	1.01	.98	40	1.02	1.02	1.04
30	.53	.63	.58	30	.60	.54	.57
20	.32	.37	.34	20	.32	.30	.33
10	.17	.26	.21	10	.20	.20	.20

NOZZLE 2" FROM PLATE.				NOZZLE 2½" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	5.45	5.47	5.46	120	5.58	5.48	5.53
110	5.00	5.04	5.02	110	5.05	5.02	5.04
100	4.37	4.44	4.40	100	4.39	4.32	4.36
90	3.79	3.79	3.79	90	3.80	3.79	3.79
80	3.18	3.26	3.22	80	3.22	3.20	3.21
70	2.64	2.62	2.63	70	2.62	2.61	2.62
60	2.10	2.12	2.11	60	2.13	2.08	2.10
50	1.60	1.60	1.60	50	1.62	1.53	1.68
40	1.09	1.14	1.11	40	1.14	1.14	1.14
30	.62	.66	.64	30	.67	.66	.66
20	.38	.40	.39	20	.42	.34	.38
10	.24	.26	.25	10	.28	.24	.26

NOZZLE NO 2, (TAPER 1-20, SQUARE INNER EDGE).
LENGTH OF NOZZLE = 5."

NOZZLE 3" FROM PLATE.				NOZZLE 4" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	5.46	5.45	5.45	120	5.27	5.32	5.29
110	4.90	4.92	4.91	110	4.84	4.73	4.77
100	4.34	4.34	4.34	100	4.26	4.21	4.23
90	3.76	3.76	3.76	90	3.66	3.64	3.65
80	3.16	3.18	3.17	80	3.04	3.06	3.05
70	2.58	2.60	2.59	70	2.52	2.48	2.50
60	2.06	2.08	2.07	60	2.01	1.98	2.01
50	1.50	1.52	1.51	50	1.46	1.46	1.46
40	1.02	1.08	1.08	40	1.03	1.04	1.03
30	.64	.58	.60	30	.56	.54	.55
20	.34	.34	.34	20	.28	.31	.30
10	.20	.20	.20	10	.16	.18	.17

NOZZLE 5" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	5.34	5.44	5.39
110	4.86	4.88	4.87
100	4.35	4.38	4.36
90	3.71	3.76	3.73
80	3.14	3.18	3.16
70	2.59	2.66	2.59
60	2.00	2.14	2.07
50	1.52	1.54	1.53
40	1.17	1.15	1.16
30	.72	.68	.70
20	.42	.44	.43
10	.27	.32	.29

NOZZLE NO 2, (TAPER 1-20, ROUNDED INNER EDGE.)
LENGTH OF NOZZLE = 5."

NOZZLE ¼" FROM PLATE.				NOZZLE 1" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.75	7.88	7.81	120	8.20	8.16	8.18
110	7.24	7.24	7.24	110	7.40	7.36	7.38
100	6.46	6.45	6.45	100	6.62	6.61	6.61
90	5.67	5.54	5.60	90	5.85	5.73	5.79
80	4.90	4.86	4.88	80	5.00	4.96	4.98
70	3.98	4.04	4.01	70	4.18	4.22	4.20
60	3.28	3.18	3.23	60	3.42	3.34	3.38
50	2.58	2.56	2.57	50	2.73	2.72	2.72
40	1.84	1.84	1.84	40	2.04	2.08	2.06
30	1.24	1.21	1.22	30	1.23	1.34	1.27
20	.64	.66	.65	20	.68	.72	.70
10	.42	.38	.40	10	.44	.39	.41

NOZZLE 2" FROM PLATE.				NOZZLE 2½" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.98	8.04	8.01	120	8.06	8.04	8.05
110	7.28	7.35	7.31	110	7.31	7.40	7.38
100	6.44	6.56	6.49	100	6.56	6.58	6.57
90	5.58	5.77	5.67	90	5.62	5.64	5.63
80	4.88	4.94	4.91	80	5.00	4.98	4.99
70	4.10	4.00	4.05	70	4.02	4.12	4.07
60	3.24	3.28	3.26	60	3.31	3.34	3.32
50	3.54	2.50	2.52	50	2.48	2.56	2.52
40	1.94	1.98	1.96	40	1.88	2.02	1.95
30	1.13	1.14	1.13	30	1.03	1.03	1.03
20	.48	.48	.48	20	.44	.46	.45
10	.22	.22	.22	10	.15	.22	.18

NOZZLE No 2, (TAPER 1-20, ROUNDED INNER EDGE).
LENGTH OF NOZZLE = 5."

NOZZLE 3" FROM PLATE.				NOZZLE 4" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	8.22	8.04	8.13	120	8.02	8.15	8.08
110	7.50	7.30	7.40	110	7.28	7.38	7.33
100	6.62	6.52	6.57	100	6.52	6.44	6.48
90	5.66	5.66	5.66	90	5.54	5.52	5.53
80	4.92	4.90	4.91	80	4.89	4.84	4.86
70	4.06	4.10	4.08	70	4.05	4.00	4.02
60	3.36	3.28	3.32	60	3.26	3.30	3.28
50	2.52	2.56	2.54	50	2.52	2.52	2.52
40	1.87	1.88	1.87	40	1.85	1.85	1.85
30	1.14	1.12	1.13	30	.98	1.08	1.03
20	.48	.50	.69	20	.38	.46	.50
10	.23	.22	.22	10	.17	.20	.19

NOZZLE 5" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	8.10	8.22	8.16
110	7.38	7.46	7.42
100	6.52	6.52	6.52
90	5.68	5.74	5.71
80	4.92	4.98	4.95
70	4.05	4.07	4.06
60	3.26	3.30	3.28
50	2.51	2.57	2.54
40	1.89	1.85	1.87
30	1.12	1.15	1.13
20	.56	.54	.55
10	.26	.26	.26

NOZZLE No 2. (TAPER 1-20, ROUNDED INNER EDGE.)
LENGTH OF NOZZLE = $3\frac{1}{2}$".

NOZZLE $\frac{1}{4}$" FROM PLATE.				NOZZLE 1" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.98	8.16	8.08	120	8.52	8.68	8.60
110	7.38	7.52	7.45	110	7.78	7.92	7.85
100	6.60	6.72	6.66	100	7.00	7.18	7.09
90	5.78	5.92	5.85	90	6.34	6.40	6.37
80	5.10	5.18	5.14	80	5.48	5.48	5.48
70	4.40	4.48	4.44	70	4.74	4.76	4.75
60	3.48	3.66	3.57	60	4.16	4.10	4.13
50	2.68	2.94	2.80	50	3.44	3.28	3.36
40	2.40	2.36	2.38	40	2.52	2.72	2.62
30	1.70	1.60	1.65	30	1.78	1.84	1.81
20	.98	.96	.97	20	1.24	1.14	1.19
10	.68	.64	.66	10	.78	.76	.77

NOZZLE 2" FROM PLATE.				NOZZLE $2\frac{1}{2}$" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	8.82	8.78	8.80	120	8.90	8.96	8.93
110	8.08	8.18	8.13	110	8.12	8.24	8.18
100	7.32	7.26	7.29	100	7.26	7.44	7.35
90	6.44	6.48	6.46	90	6.54	6.66	6.60
80	5.64	5.62	5.63	80	5.62	5.76	5.69
70	4.90	4.92	4.91	70	4.90	5.04	4.97
60	4.18	4.14	4.16	60	4.16	4.30	4.23
50	3.28	3.34	3.31	50	3.32	3.62	3.47
40	2.66	2.72	2.69	40	2.76	2.68	2.72
30	1.92	2.14	2.05	30	2.02	1.82	1.92
20	1.08	1.28	1.13	20	1.26	1.16	1.21
10	.56	.90	.74	10	.84	.76	.80

NOZZLE No 2. (TAPER 1-20, ROUNDED INNER EDGE.)
LENGTH OF NOZZLE = $3\frac{1}{2}$".

NOZZLE 3" FROM PLATE.				NOZZLE 4" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE. IMPACT.
120	8.70	8.94	8.77	120	8.74	8.78	8.76
110	7.98	8.02	8.00	110	7.96	8.00	7.98
100	7.18	7.26	7.22	100	7.12	7.22	7.17
90	6.26	6.32	6.29	90	6.26	6.40	6.33
80	5.34	5.38	5.36	80	5.56	5.56	5.56
70	4.64	4.68	4.66	70	4.74	4.74	4.74
60	3.92	4.02	3.97	60	4.04	4.04	4.04
50	3.18	3.20	3.19	50	3.20	3.26	3.23
40	2.54	2.66	2.60	40	2.54	2.56	2.55
30	1.64	1.76	1.70	30	1.74	1.78	1.76
20	.96	.94	.95	20	.98	.96	.97
10	.60	.58	.59	10	.60	.60	.60

NOZZLE 5" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	8.60	8.72	8.66
110	7.86	7.90	7.88
100	6.98	7.12	7.05
90	6.20	6.20	6.20
80	5.40	5.48	5.44
70	4.76	4.60	4.68
60	3.92	3.90	3.91
50	3.22	3.22	3.22
40	2.60	2.64	2.62
30	1.76	1.64	1.70
20	.92	.94	.93
10	.58	.62	.60

SUMMARY.

NOZZLE NO 2, TAPER 1-20.

IMPACT.

LENGTH OF NOZZLE = 5". SQUARE INNER EDGE.

PRESS.	DISTANCE OF NOZZLE FROM PLATE.						
	¼"	1"	2"	2½"	3"	4"	5"
120	5.07	5.38	5.46	5.53	5.45	5.29	5.39
110	4.63	4.87	5.02	5.04	4.91	4.77	4.87
100	4.07	4.27	4.40	4.36	4.34	4.23	4.36
90	3.49	3.72	3.79	3.79	3.76	3.65	3.73
80	2.89	3.08	3.22	3.21	3.17	3.05	3.16
70	2.33	2.55	2.63	2.62	2.59	2.50	2.59
60	1.83	1.98	2.11	2.10	2.07	2.01	2.07
50	1.33	1.50	1.60	1.68	1.51	1.46	1.53
40	.98	1.04	1.11	1.14	1.08	1.03	1.16
30	.58	.57	.64	.66	.60	.55	.70
20	.34	.33	.39	.38	.34	.30	.43
10	.21	.20	.25	.26	.20	.17	.29

IMPACT.

LENGTH OF NOZZLE = 5". ROUNDED INNER EDGE.

PRESS.	DISTANCE OF NOZZLE FROM PLATE.						
	¼"	1"	2"	2½"	3"	4"	5"
120	7.81	8.18	8.01	8.05	8.13	8.08	8.16
110	7.24	7.38	7.31	7.38	7.40	7.33	7.42
100	6.45	6.61	6.49	6.57	6.57	6.48	6.52
90	5.60	5.79	5.67	5.63	5.66	5.53	5.71
80	4.88	4.98	4.91	4.99	4.91	4.86	4.95
70	4.01	4.20	4.05	4.07	4.08	4.02	4.06
60	3.23	3.38	3.26	3.32	3.32	3.28	3.28
50	2.57	2.72	2.52	2.52	2.54	2.52	2.54
40	1.84	2.06	1.96	1.95	1.87	1.85	1.87
30	1.22	1.27	1.13	1.03	1.13	1.03	1.13
20	.65	.70	.48	.45	.59	.50	.55
10	.40	.41	.22	.18	.22	.19	.26

SUMMARY.

NOZZLE NO 2; TAPER 1-20.

IMPACT.

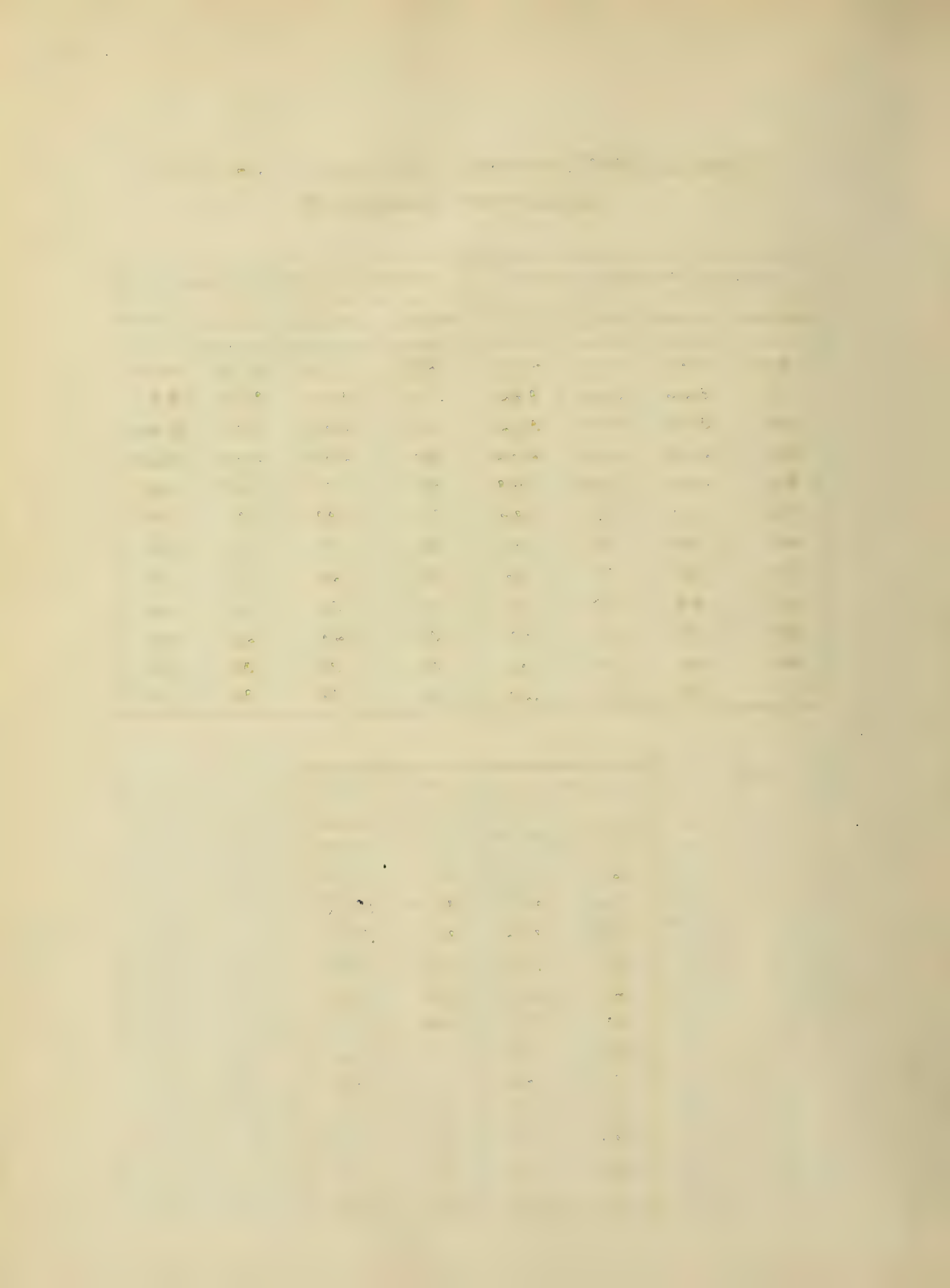
LENGTH OF NOZZLE = $3\frac{1}{2}$". ROUNDED INNER EDGE.

PRESS.	DISTANCE OF NOZZLE FROM PLATE.						
	¼"	1"	2"	2½"	3"	4"	5"
120	8.08	8.60	8.80	8.93	8.77	8.76	8.66
110	7.45	7.85	8.13	8.18	8.00	7.98	7.88
100	6.66	7.09	7.29	7.35	7.22	7.17	7.05
90	5.85	6.37	6.46	6.60	6.29	6.33	6.20
80	5.14	5.48	5.63	5.69	5.36	5.56	5.44
70	4.44	4.75	4.91	4.97	4.66	4.74	4.68
60	3.57	4.13	4.16	4.23	3.97	4.04	3.91
50	2.80	3.36	3.31	3.47	3.19	3.23	3.22
40	2.38	2.62	2.69	2.72	2.60	2.55	2.62
30	1.65	1.81	2.05	1.92	1.70	1.76	1.70
20	.97	1.19	1.13	1.21	.95	.97	.93
10	.66	.77	.74	.80	.59	.60	.60

NOZZLE NO. 3. (TAPER 1-10, SQUARE INNER EDGE). LENGTH OF NOZZLE = 6".

NOZZLE $\frac{1}{4}$" FROM PLATE.				NOZZLE 1" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	3.52	3.51	3.51	120	3.92	3.96	3.94
110	3.02	3.00	3.01	110	3.42	3.40	3.41
100	2.59	2.54	2.56	100	2.86	2.90	2.88
90	2.19	2.18	2.18	90	2.28	2.30	2.29
80	1.61	1.68	1.64	80	1.76	1.78	1.77
70	1.27	1.22	1.24	70	1.35	1.31	1.34
60	.92	.98	.96	60	1.00	.99	.99
50	.80	.79	.79	50	.66	.69	.67
40	.66	.68	.67	40	.47	.48	.47
30	.50	.50	.50	30	.36	.36	.36
20	.36	.37	.36	20	.28	.26	.27
10	.24	.25	.24	10	.18	.16	.17

NOZZLE 2" FROM PLATE.				NOZZLE 2$\frac{1}{2}$" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	4.00	3.97	3.98	120	3.88	3.88	3.88
110	3.40	3.35	3.38	110	3.36	3.33	3.34
100	2.89	2.82	2.85	100	2.76	2.77	2.76
90	2.30	2.30	2.30	90	2.23	2.25	2.24
80	1.76	1.76	1.76	80	1.66	1.69	1.68
70	1.34	1.23	1.28	70	1.22	1.20	1.21
60	.88	.87	.88	60	.82	.85	.84
50	.64	.62	.63	50	.55	.53	.54
40	.48	.47	.47	40	.40	.38	.39
30	.36	.35	.35	30	.25	.26	.26
20	.27	.21	.25	20	.17	.17	.17
10	.21	.16	.18	10	.10	.12	.11



NOZZLE NO 3. (SQUARE INNER EDGE, TAPER 1-10). LENGTH OF NOZZLE = 6".

NOZZLE 3" FROM PLATE.				NOZZLE 4" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	4.20	4.10	4.15	120	4.00	4.10	4.05
110	3.66	3.58	3.62	110	3.44	3.50	3.47
100	3.10	2.97	3.02	100	2.85	3.06	2.96
80	2.48	2.44	2.46	90	2.38	2.48	2.42
80	2.02	1.82	1.93	80	1.79	1.87	1.83
70	1.42	1.35	1.38	70	1.33	1.36	1.34
60	1.05	.97	1.05	60	.90	1.02	.96
50	.81	.75	.78	50	.66	.75	.70
40	.63	.58	.60	40	.55	.58	.56
30	.47	.47	.47	30	.43	.45	.44
20	.36	.36	.36	20	.37	.39	.38
10	.28	.30	.29	10	.32	.30	.31

NOZZLE $4\frac{1}{2}$" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	4.10	4.16	4.13
110	3.57	3.57	3.57
100	3.18	3.19	3.18
90	2.50	2.57	2.54
80	2.00	1.90	1.98
70	1.51	1.38	1.47
60	1.15	1.10	1.12
50	.88	.77	.83
40	.71	.63	.67
30	.58	.52	.55
20	.48	.43	.45
10	.40	.39	.39

Nozzle No 3, (taper 1-10, square inner edge).
Length of Nozzle = 5."

Nozzle $\frac{1}{4}$" from plate.				Nozzle 1" from plate.			
Press.	Impact.	Impact.	Average Impact.	Press.	Impact.	Impact.	Average Impact.
120	3.81	3.90	3.86	120	-----	------	-----
110	3.36	3.37	3.36	110	4.44	4.43	4.44
100	2.69	2.68	2.68	100	3.93	3.85	3.89
90	2.30	2.22	2.26	90	3.36	3.29	3.33
80	1.79	1.81	1.80	80	2.68	2.71	2.69
70	1.38	1.38	1.38	70	2.10	2.18	2.14
60	1.03	1.03	1.03	60	1.68	1.70	1.69
50	.75	.75	.75	50	1.33	1.27	1.30
40	.66	.56	.56	40	1.04	1.00	1.02
30	.41	.43	.42	30	.77	.77	.77
20	.23	.26	.24	20	.59	.65	.62
10	.15	.15	.15	10	.51	.58	.54

Nozzle 2" from plate.				Nozzle $2\frac{1}{2}$" from plate.			
Press.	Impact.	Impact.	Average Impact.	Press.	Impact.	Impact	Average Impact.
120	5.00	5.10	5.05	120	4.85	4.78	4.82
110	4.56	5.60	4.58	110	4.27	4.20	4.23
100	3.97	4.05	4.01	100	3.71	3.68	3.69
90	3.40	3.42	3.41	90	3.05	3.04	3.04
80	2.76	2.84	2.80	80	2.47	2.45	2.46
70	2.24	2.28	2.76	70	1.95	1.94	1.94
60	1.71	1.75	1.73	60	1.51	1.46	1.48
50	1.34	1.35	1.34	50	1.06	.92	.99
40	1.05	1.00	1.03	40	.77	.68	.72
30	.84	.82	.83	30	.53	.42	.47
20	.67	.68	.67	20	.41	.31	.36
10	.62	.61	.61	10	.31	.22	.27

NOZZLE NO 3. (TAPER 1-10, SQUARE INNER EDGE).
LENGTH OF NOZZLE = 5."

NOZZLE 3" FROM PLATE.				NOZZLE 4" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	5.08	5.01	5.03	120	4.78	4.76	4.77
110	4.52	4.50	4.51	110	4.18	4.12	4.14
100	3.91	3.88	3.89	100	3.48	3.58	3.51
90	3.35	3.35	3.35	90	2.94	2.95	2.94
80	2.64	2.67	2.65	80	2.34	2.35	2.34
70	2.17	2.16	2.16	70	1.78	1.88	1.83
60	1.72	1.70	1.71	60	1.29	1.32	1.30
50	1.30	1.32	1.31	50	.90	.96	.93
40	.97	.97	.97	40	.67	.64	.66
30	.77	.76	.76	30	.43	.41	.42
20	.62	.65	.63	20	.34	.28	.31
10	.56	.56	.56	10	.25	.22	.23

NOZZLE 5" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	4.60	4.64	4.62
110	4.04	4.08	4.06
100	3.43	3.52	3.47
90	2.85	3.87	2.86
80	2.26	2.30	2.28
70	1.76	1.88	1.80
60	1.37	1.28	1.32
50	.89	.91	.90
40	.64	.66	.65
30	.44	.44	.44
20	.32	.30	.31
10	.25	.21	.23

NOZZLE NO. 3, (TAPER 1-10, ROUNDED INNER EDGE). LENGTH OF NOZZLE = 5."

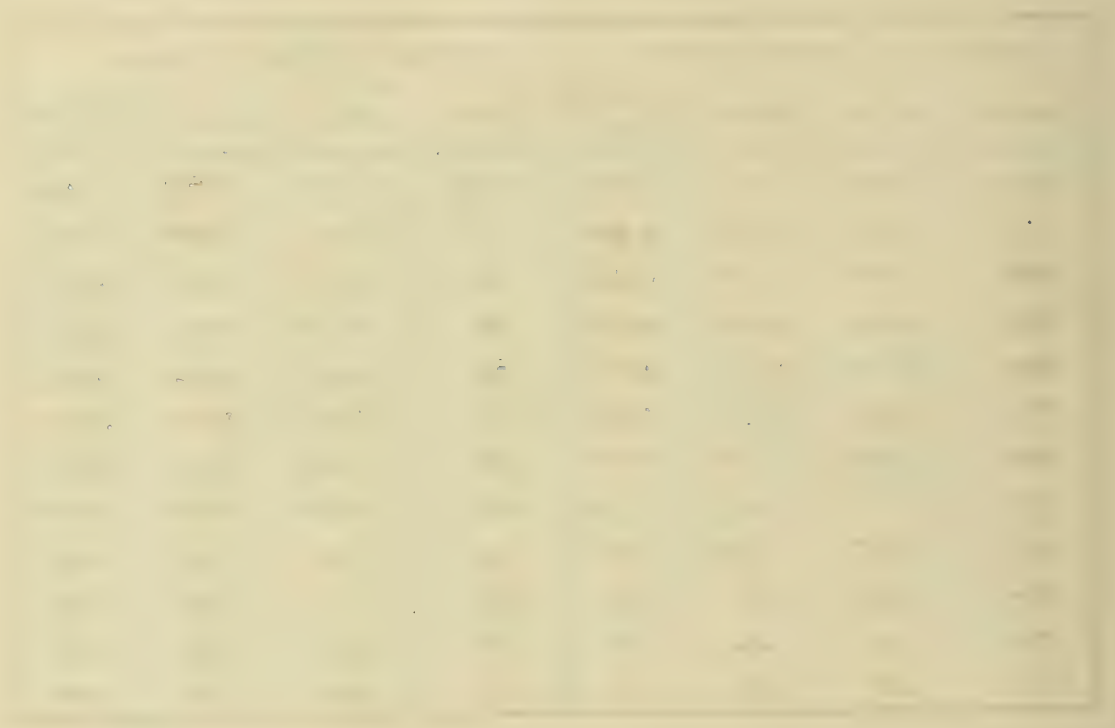
NOZZLE $\frac{1}{4}$" FROM PLATE.				NOZZLE 1" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	------	------	-------	120	7.26	7.26	7.26
110	5.85	5.88	5.86	110	6.51	6.48	6.50
100	5.05	5.16	5.10	100	5.74	5.72	5.73
90	4.33	4.53	4.43	90	4.88	4.90	4.89
80	3.70	3.68	3.69	80	4.09	4.18	4.13
70	2.92	2.98	2.95	70	3.36	3.30	3.33
60	2.26	2.35	2.30	60	2.60	2.66	2.62
50	1.74	1.80	1.77	50	1.98	1.98	1.98
40	1.26	1.30	1.28	40	1.44	1.48	1.46
30	.83	.86	.84	30	.92	.90	.91
20	.60	.60	.60	20	.66	.70	.68
10	.44	.46	.45	10	.55	.58	.56

NOZZLE 2" FROM PLATE.				NOZZLE 2$\frac{1}{2}$" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.36	7.38	7.37	120	6.93	6.98	6.95
110	6.52	6.62	6.57	110	6.20	6.22	6.21
100	5.76	5.78	5.77	100	5.38	5.40	5.39
90	4.94	4.91	4.93	90	4.52	4.64	4.58
80	4.12	4.14	4.13	80	3.78	3.84	3.81
70	3.36	3.38	3.37	70	3.02	3.00	3.01
60	2.67	2.60	2.63	60	2.28	2.32	2.30
50	2.00	1.92	1.96	50	1.82	1.62	1.72
40	1.40	1.42	1.41	40	1.18	1.06	1.12
30	.94	.84	.86	30	.63	.61	.62
20	.68	.66	.67	20	.42	.32	.37
10	.56	.52	.54	10	.26	.22	.24

NOZZLE No 3, (TAPER 1-10, ROUNDED INNER EDGE.)
LENGTH OF NOZZLE = 5."

NOZZLE 3" FROM PLATE.				NOZZLE 4" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	6.92	-----	6.92	120	6.88	6.90	6.89
110	6.09	6.07	6.08	110	6.10	6.08	6.09
100	5.32	5.30	5.31	100	5.31	5.33	5.32
90	4.52	4.54	4.53	90	4.52	4.46	4.50
80	3.54	3.72	3.63	80	3.68	3.62	3.65
70	2.82	2.94	2.88	70	2.94	2.94	2.94
60	2.08	2.30	2.19	60	2.22	2.20	2.21
50	1.51	1.60	1.55	50	1.58	1.49	1.54
40	1.05	.98	1.01	40	1.04	1.00	1.02
30	.51	.54	.53	30	----	.56	.56
20	.22	.26	.24	20	.35	.35	.35
10	.12	.12	.12	10	.20	.20	.20

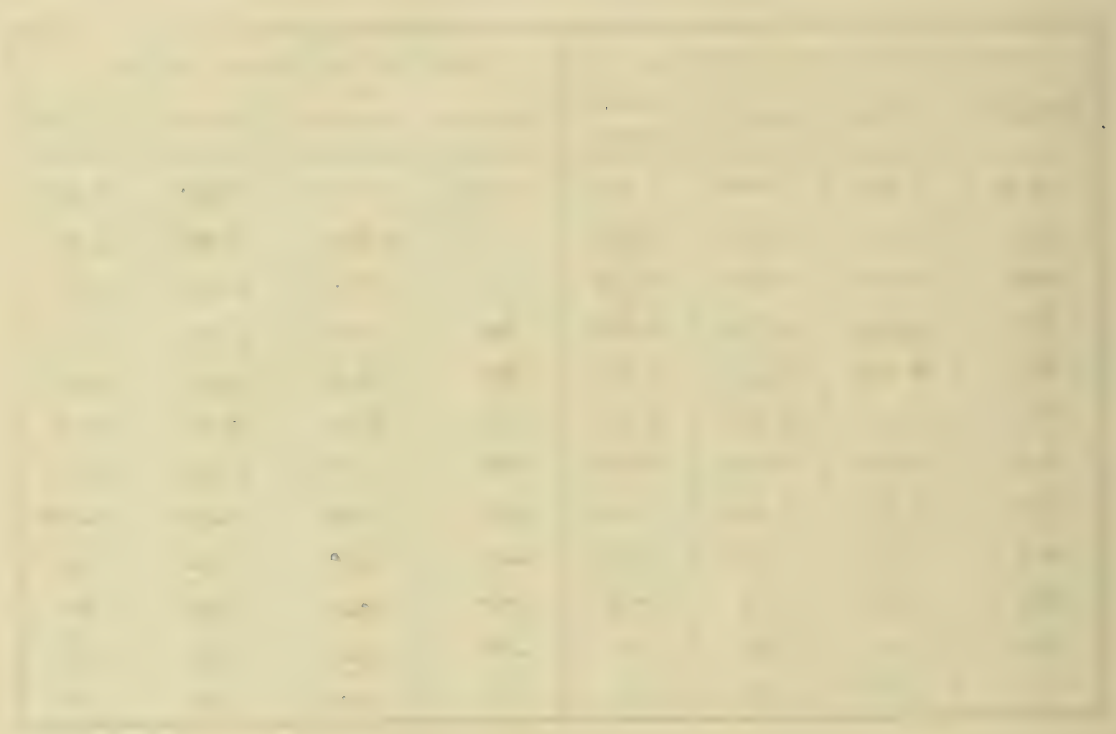
NOZZLE 5" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	6.78	6.70	6.74
110	5.90	5.90	5.90
100	5.12	5.12	5.12
90	4.41	4.39	4.40
80	3.62	3.62	3.62
70	2.78	2.77	2.77
60	2.14	2.16	2.15
50	1.50	1.46	1.48
40	1.00	.98	.99
30	.54	.52	.53
20	.30	.30	.30
10	.13	.14	.14



NOZZLE NO 3. (TAPER 1-10, ROUNDED INNER EDGE.)
LENGTH OF NOZZLE = $3\frac{1}{2}$".

NOZZLE $\frac{1}{4}$" FROM PLATE.				NOZZLE 1" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT	AVERAGE IMPACT.
120	7.24	7.24	7.24	120	7.76	7.88	7.80
110	6.26	6.42	6.34	110	7.04	7.08	7.06
100	5.44	5.60	5.52	100	6.18	6.24	6.21
90	4.84	4.90	4.87	90	5.50	5.52	5.51
80	3.98	3.96	3.97	80	4.70	4.76	4.73
70	3.08	2.94	3.01	70	3.94	3.92	3.93
60	2.42	2.48	2.45	60	3.08	3.24	3.16
50	1.70	1.78	1.74	50	2.50	2.58	2.54
40	1.18	1.22	1.20	40	1.86	1.92	1.91
30	.68	.78	.73	30	1.10	1.18	1.09
20	.47	.48	.47	20	.64	.64	.64
10	.33	.31	.32	10	.34	.42	.38

NOZZLE 2" FROM PLATE.				NOZZLE $2\frac{1}{2}$" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.94	7.98	7.96	120	7.94	7.98	7.96
110	7.16	7.20	7.18	110	7.18	7.24	7.21
100	6.38	6.42	6.40	100	6.38	6.48	6.43
90	5.58	5.62	5.60	90	5.56	5.66	5.61
80	4.80	4.84	4.82	80	4.88	4.90	4.89
70	3.96	3.94	3.95	70	4.04	4.00	4.02
60	3.22	3.18	3.20	60	3.20	3.28	3.24
50	2.52	2.66	2.59	50	2.58	2.52	2.55
40	1.92	1.92	1.92	40	1.96	1.92	1.94
30	1.12	1.14	1.13	30	1.18	1.30	1.24
20	.58	.56	.57	20	.62	.60	.61
10	.36	.38	.37	10	.44	.40	.42



NOZZLE No 3. (TAPER 1-10, ROUNDED INNER EDGE.)
LENGTH OF NOZZLE = $3\frac{1}{2}$".

NOZZLE 3" FROM PLATE.				NOZZLE 4" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.	PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.84	7.78	7.81	120	7.58	7.60	7.59
110	7.06	7.06	7.06	110	6.82	6.82	6.82
100	6.20	6.30	6.25	100	5.96	6.02	5.99
90	5.38	5.50	5.44	90	5.06	5.20	5.13
80	4.68	4.60	4.64	80	4.68	4.56	5.62
70	3.74	3.84	3.79	70	3.56	3.70	3.64
60	2.94	3.04	2.99	60	2.94	2.90	2.92
50	2.22	2.26	2.24	50	2.24	2.32	2.28
40	1.70	1.72	1.71	40	1.58	1.66	1.62
30	.82	.96	.89	30	.82	.92	.87
20	.32	.36	.34	20	.32	.42	.37
10	.14	.18	.16	10	.10	.22	.16

NOZZLE 5" FROM PLATE.			
PRESS.	IMPACT.	IMPACT.	AVERAGE IMPACT.
120	7.78	7.64	7.73
110	7.00	6.84	6.92
100	6.18	6.18	6.18
90	5.36	5.28	5.32
80	4.68	4.58	4.63
70	3.86	3.62	3.74
60	3.00	3.00	3.00
50	2.28	2.14	2.21
40	1.64	1.58	1.61
30	.92	.78	.85
20	.34	.30	.32
10	.14	.14	.14

SUMMARY.

NOZZLE NO 3; TAPER 1-10.

IMPACT.

LENGTH OF NOZZLE = 5". ROUNDED INNER EDGE.

PRESS.	DISTANCE OF NOZZLE FROM PLATE.						
	¼".	1".	2".	2½".	3".	4".	5".
120	----	7.26	7.37	6.95	6.92	6.89	6.74
110	5.86	6.50	6.57	6.21	6.08	6.09	5.90
100	5.10	5.73	5.77	5.39	5.31	5.32	5.12
90	4.43	4.89	4.93	4.58	4.53	4.50	4.40
80	3.69	4.13	4.13	3.81	3.63	3.65	3.62
70	2.95	3.33	3.37	3.01	2.88	2.94	2.77
60	2.30	2.62	2.63	2.30	2.19	2.21	2.15
50	1.77	1.98	1.96	1.72	1.55	1.54	1.48
40	1.28	1.46	1.41	1.12	1.01	1.02	.99
30	.84	.91	.86	.62	.53	.56	.53
20	.60	.68	.67	.37	.24	.35	.30
10	.45	.56	.54	.24	.12	.20	.14

IMPACT.

LENGTH OF NOZZLE = 3½". ROUNDED INNER EDGE.

PRESS.	DISTANCE OF NOZZLE FROM PLATE.						
	¼".	1".	2".	2½".	3".	4".	5".
120	7.24	7.80	7.96	7.96	7.81	7.59	7.73
110	6.34	7.06	7.18	7.21	7.06	6.82	6.92
100	5.52	6.21	6.40	6.43	6.25	5.99	6.18
90	4.87	5.51	5.60	5.61	5.44	5.13	5.32
80	3.97	4.73	4.82	4.89	4.64	5.62	4.63
70	3.01	3.93	3.95	4.02	3.79	3.64	3.74
60	2.45	3.16	3.20	3.24	2.99	2.92	3.06
50	1.74	2.54	2.59	2.55	2.24	2.28	2.21
40	1.20	1.91	1.92	1.94	1.71	1.62	1.61
30	.73	1.09	1.13	1.24	.89	.87	.85
20	.47	.64	.57	.61	.34	.37	.32
10	.32	.38	.37	.42	.16	.16	.14

SUMMARY.
NOZZLE NO3; TAPER 1-10.

IMPACT.

LENGTH OF NOZZLE = 6". SQUARE INNER EDGE.

PRESS.	DISTANCE OF PLATE FROM NOZZLE.						
	¼".	1".	2".	2½".	3".	4".	5".
120	3.51	3.94	3.98	3.88	4.15	4.05	4.13
110	3.01	3.41	3.38	3.34	3.62	3.47	3.57
100	2.56	2.88	2.85	2.76	3.02	2.96	3.18
90	2.18	2.29	2.30	2.34	2.46	2.42	2.54
80	1.64	1.77	1.76	1.68	1.93	1.83	1.98
70	1.24	1.34	1.28	1.21	1.38	1.34	1.47
60	.96	.99	.88	.84	1.05	.96	1.12
50	.79	.67	.63	.54	.78	.70	.83
40	.67	.47	.47	.39	.60	.56	.67
30	.50	.36	.35	.26	.47	.44	.55
20	.36	.27	.25	.17	.36	.38	.45
10	.24	.17	.18	.11	.29	.31	.39

IMPACT.

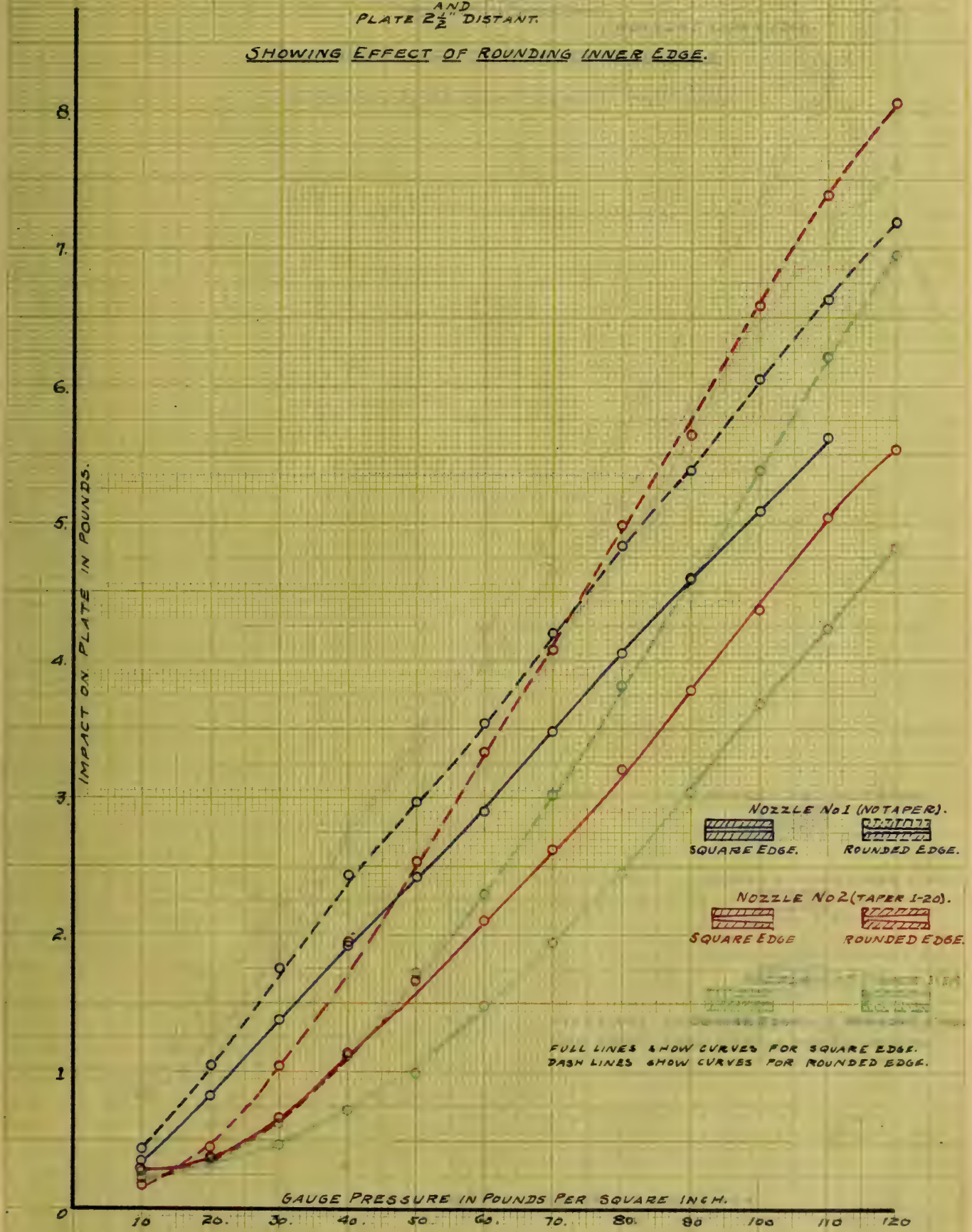
LENGTH OF NOZZLE = 5". SQUARE INNER EDGE.

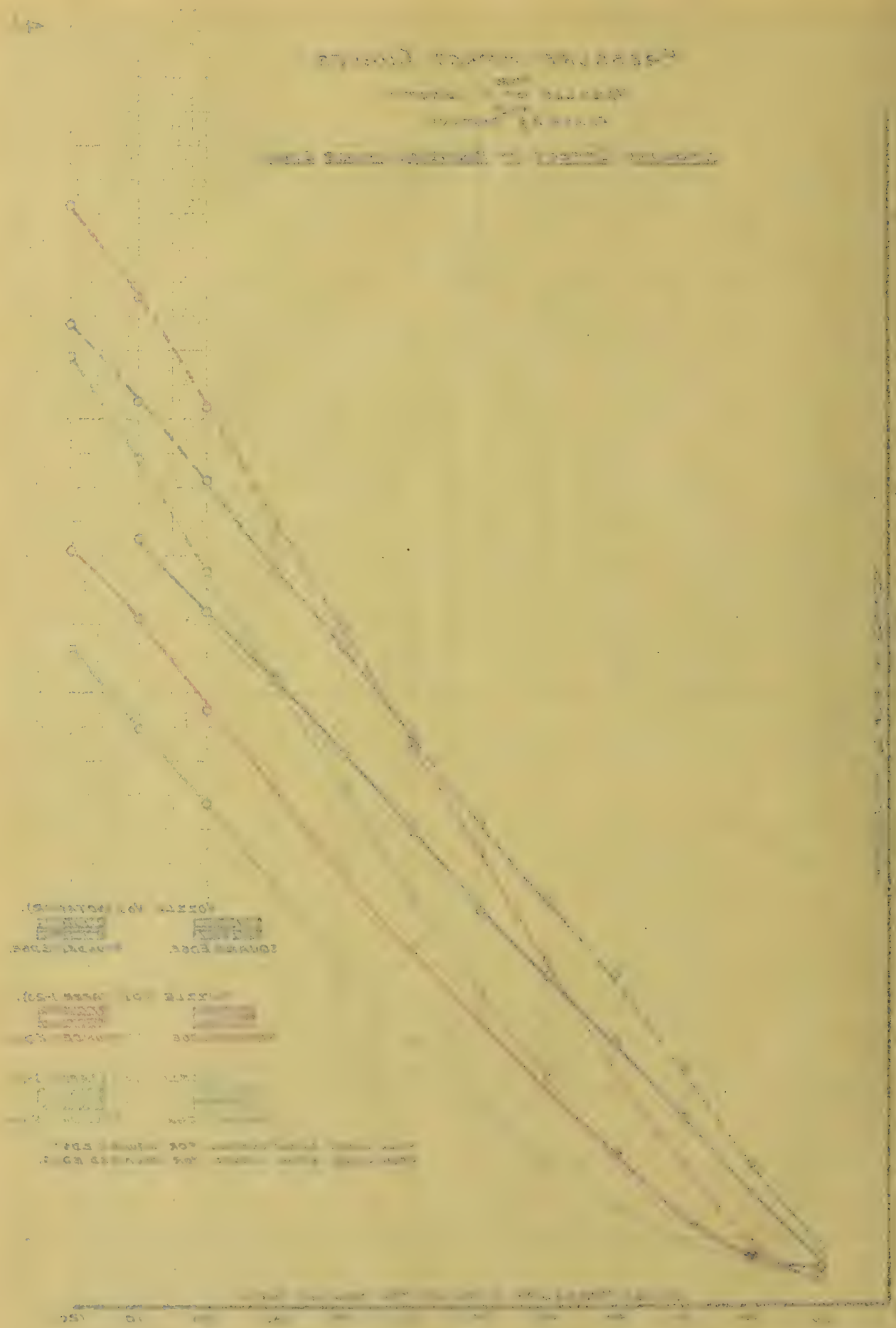
PRESS.	DISTANCE OF NOZZLE FROM PLATE.						
	¼".	1".	2".	2½".	3".	4".	5".
120	3.86	------	5.05	4.82	5.03	4.77	4.62
110	3.36	4.44	4.58	4.23	4.51	4.14	4.06
100	2.68	3.89	4.01	3.69	3.89	3.51	3.47
90	2.26	3.33	3.41	3.04	3.35	2.94	2.86
80	1.80	2.69	2.80	2.46	2.66	2.34	2.28
70	1.38	2.14	2.76	1.94	2.16	1.83	1.80
60	1.03	1.69	1.73	1.48	1.71	1.30	1.32
50	.75	1.30	1.34	.99	1.31	.93	.90
40	.56	1.02	1.03	.72	96	.66	.65
30	.42	.77	.83	.47	.76	.42	.44
20	.24	.62	.67	.36	.63	.31	.31
10	.15	.54	.61	.27	.56	.23	.23

PRESSURE-IMPACT CURVES.

FOR NOZZLES OF 3" LENGTH AND PLATE 2½" DISTANT.

SHOWING EFFECT OF ROUNDING INNER EDGE.



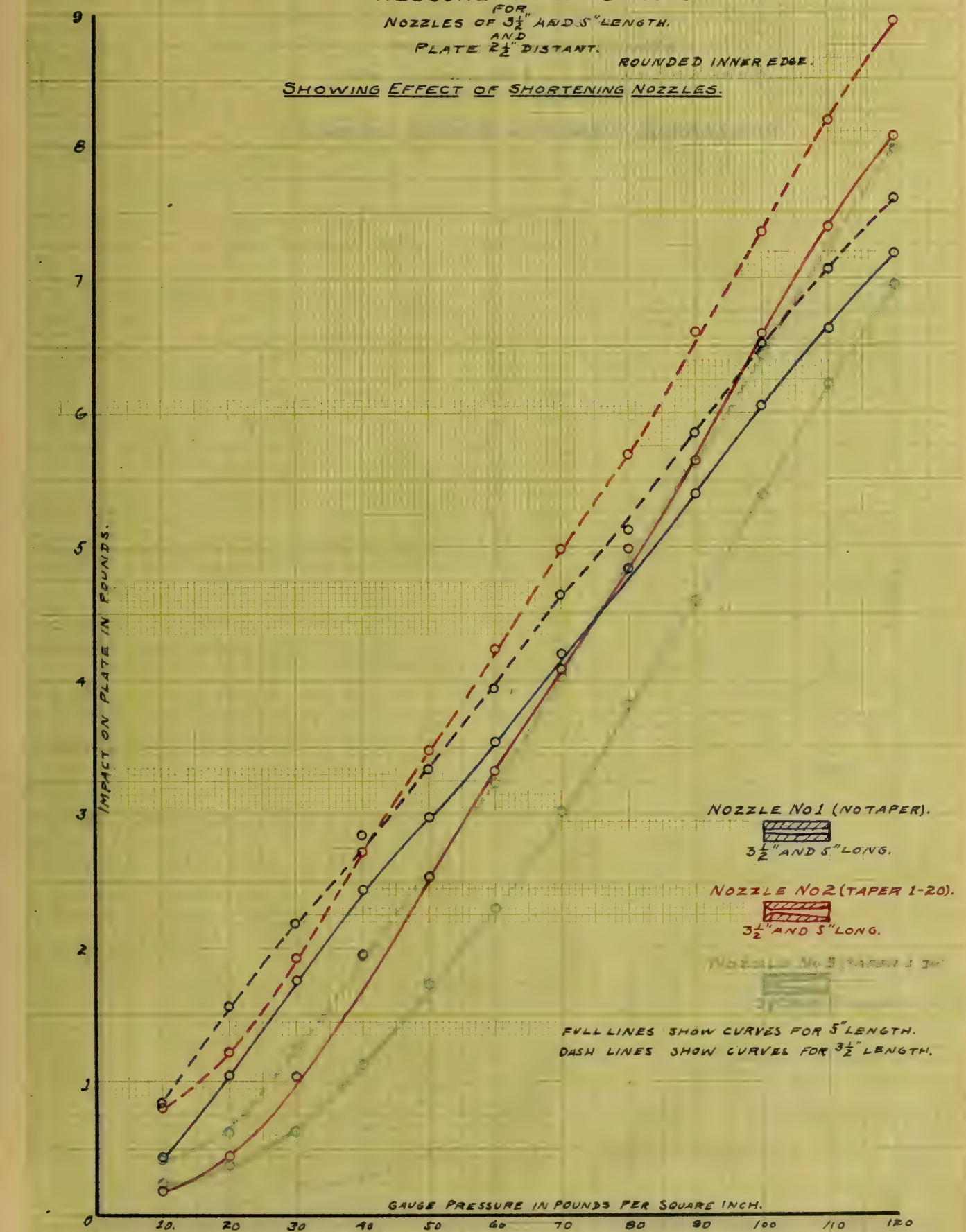


PRESSURE - IMPACT CURVES.

FOR
NOZZLES OF $3\frac{1}{2}$" AND 5" LENGTH.
AND
PLATE $2\frac{1}{2}$" DISTANT.

ROUNDED INNER EDGE.

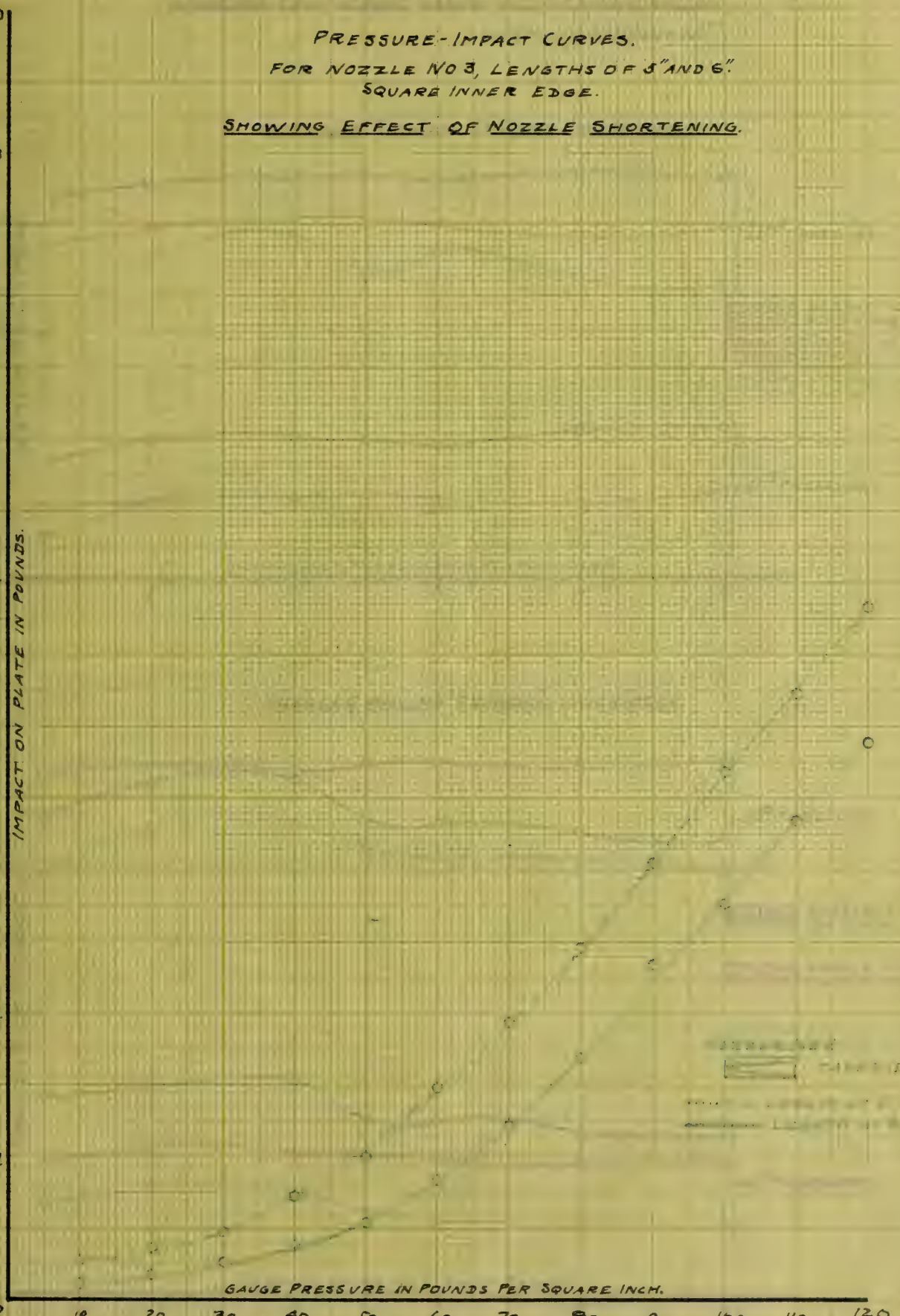
SHOWING EFFECT OF SHORTENING NOZZLES.



PRESSURE-IMPACT CURVES.

FOR NOZZLE NO 3, LENGTHS OF 3" AND 6".
SQUARE INNER EDGE.

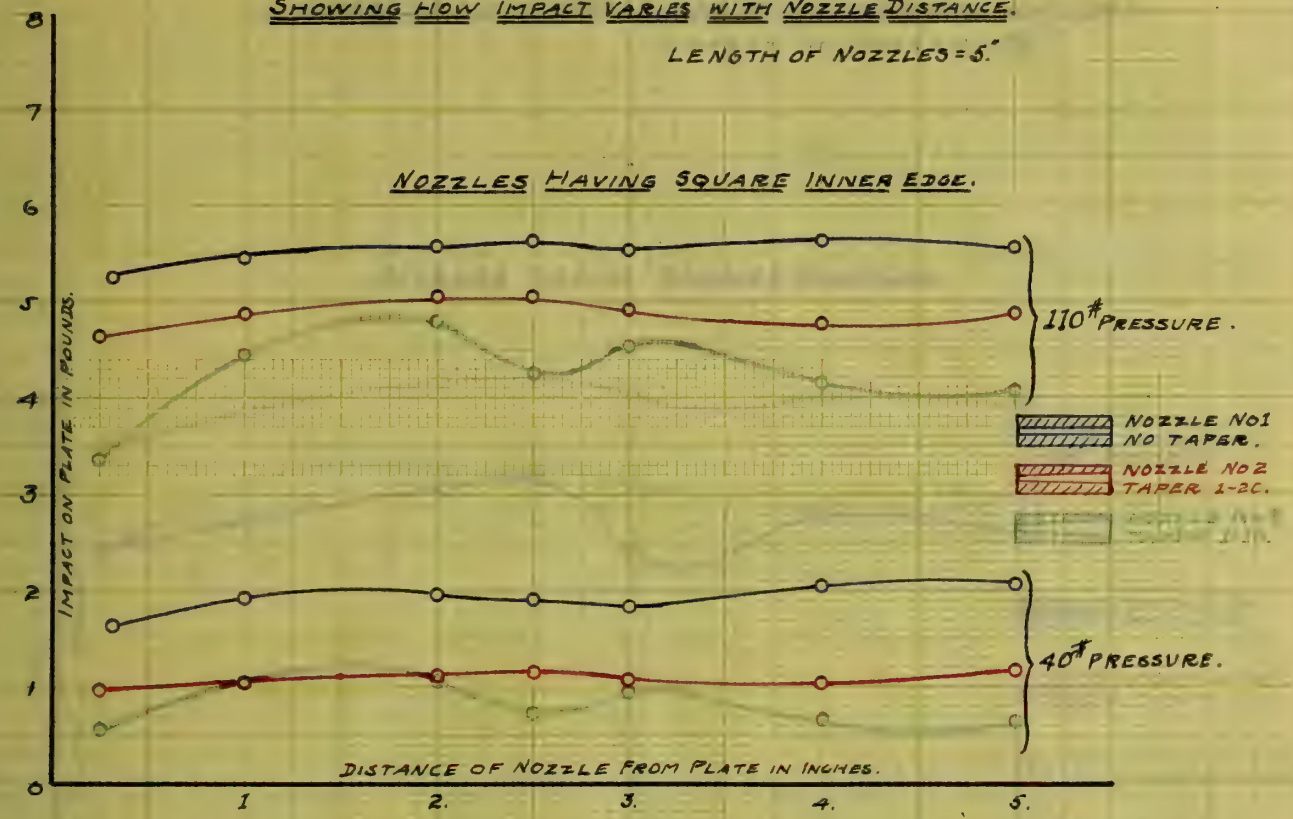
SHOWING EFFECT OF NOZZLE SHORTENING.

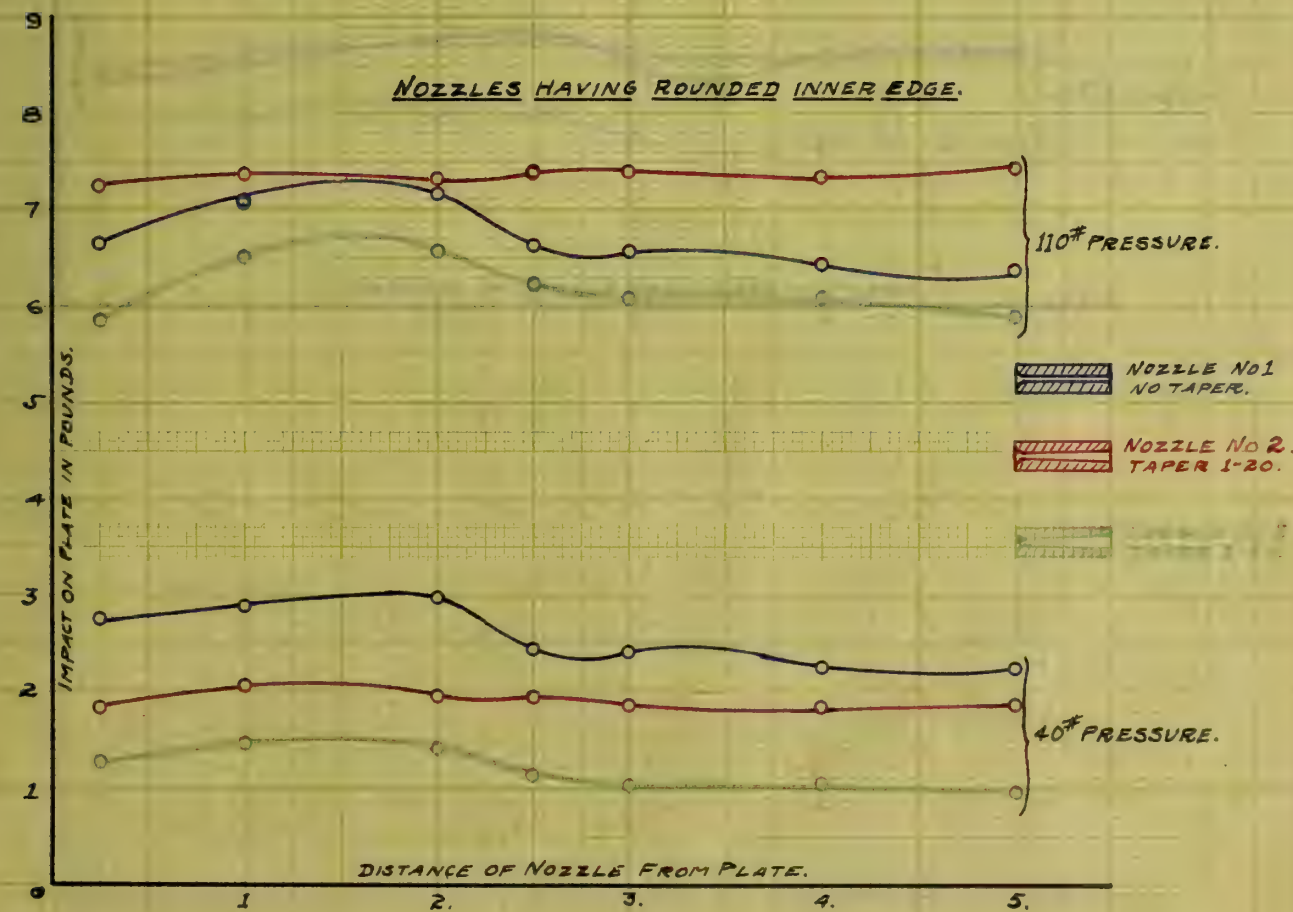


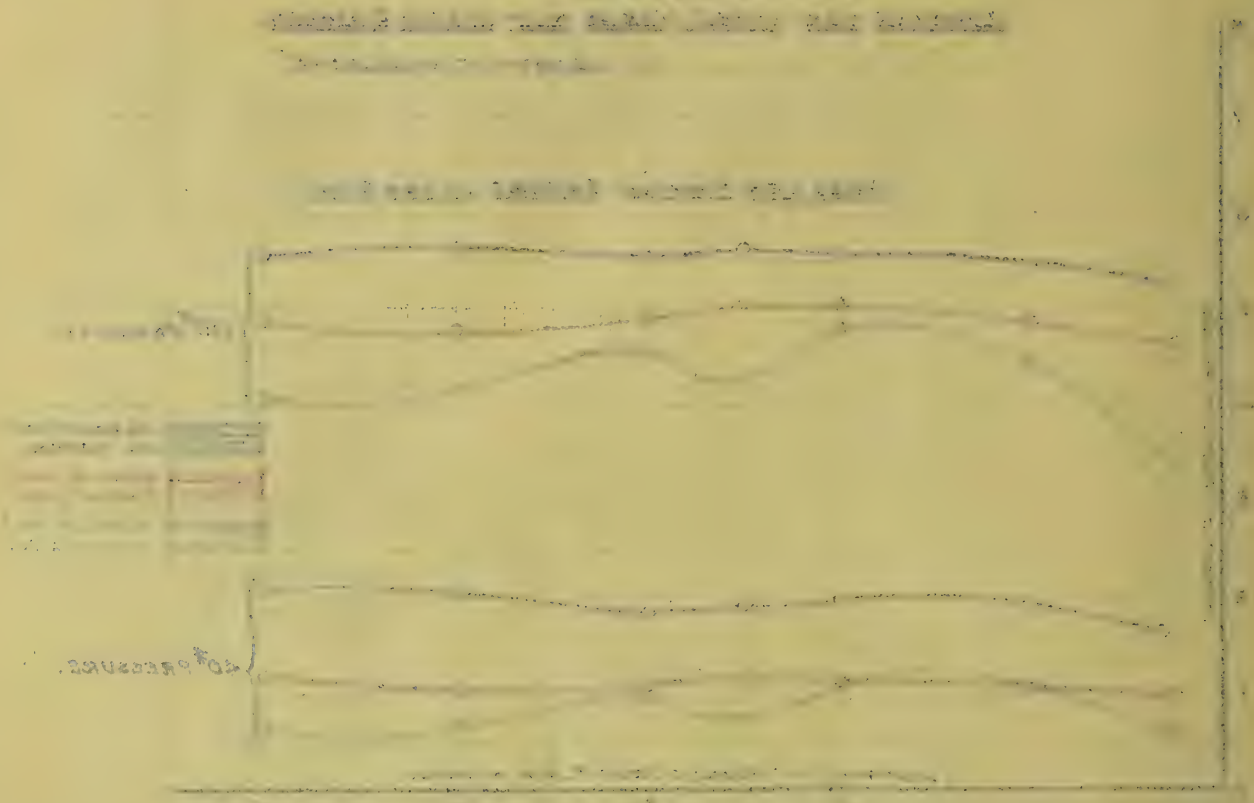
IMPACT CURVES.

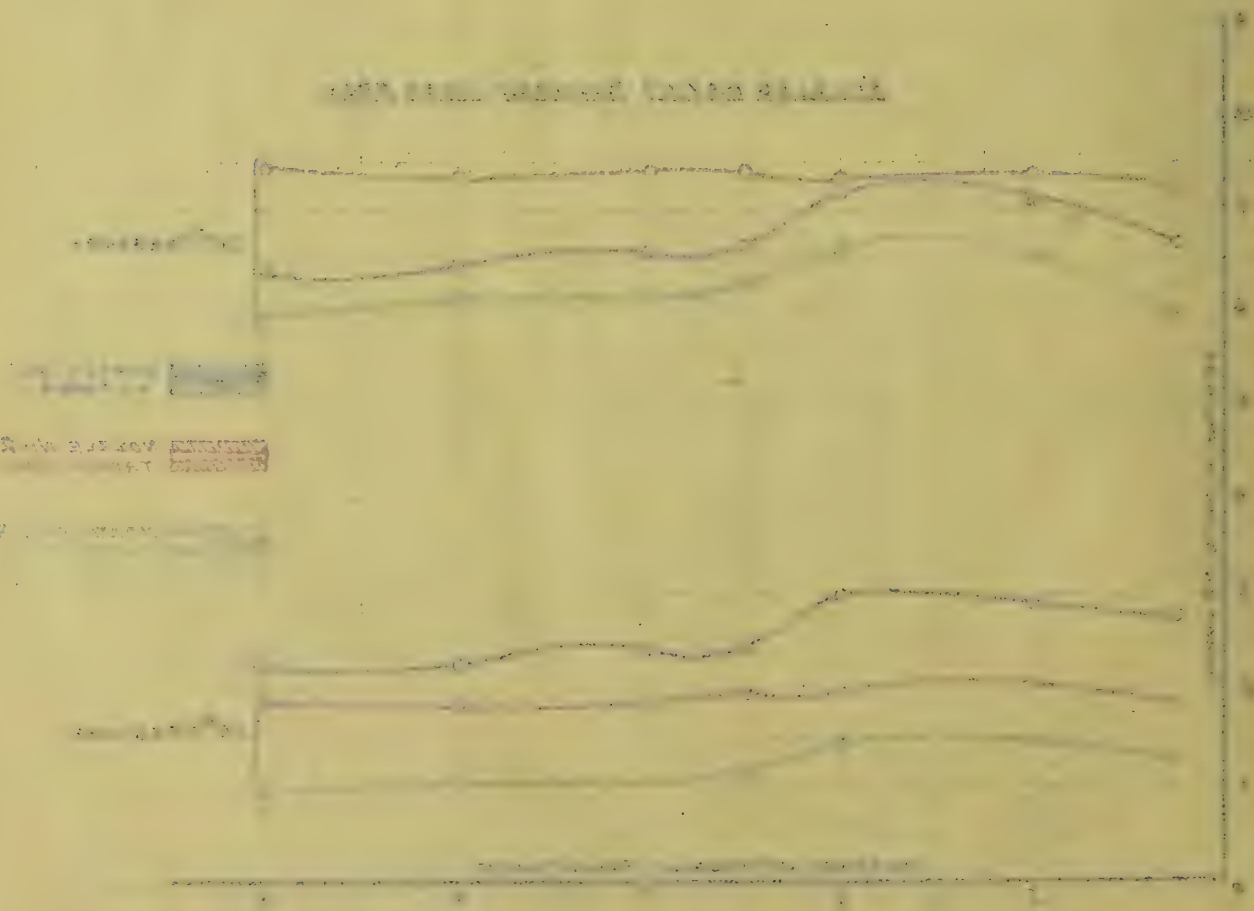
SHOWING HOW IMPACT VARIES WITH NOZZLE DISTANCE.

LENGTH OF NOZZLES = 5".







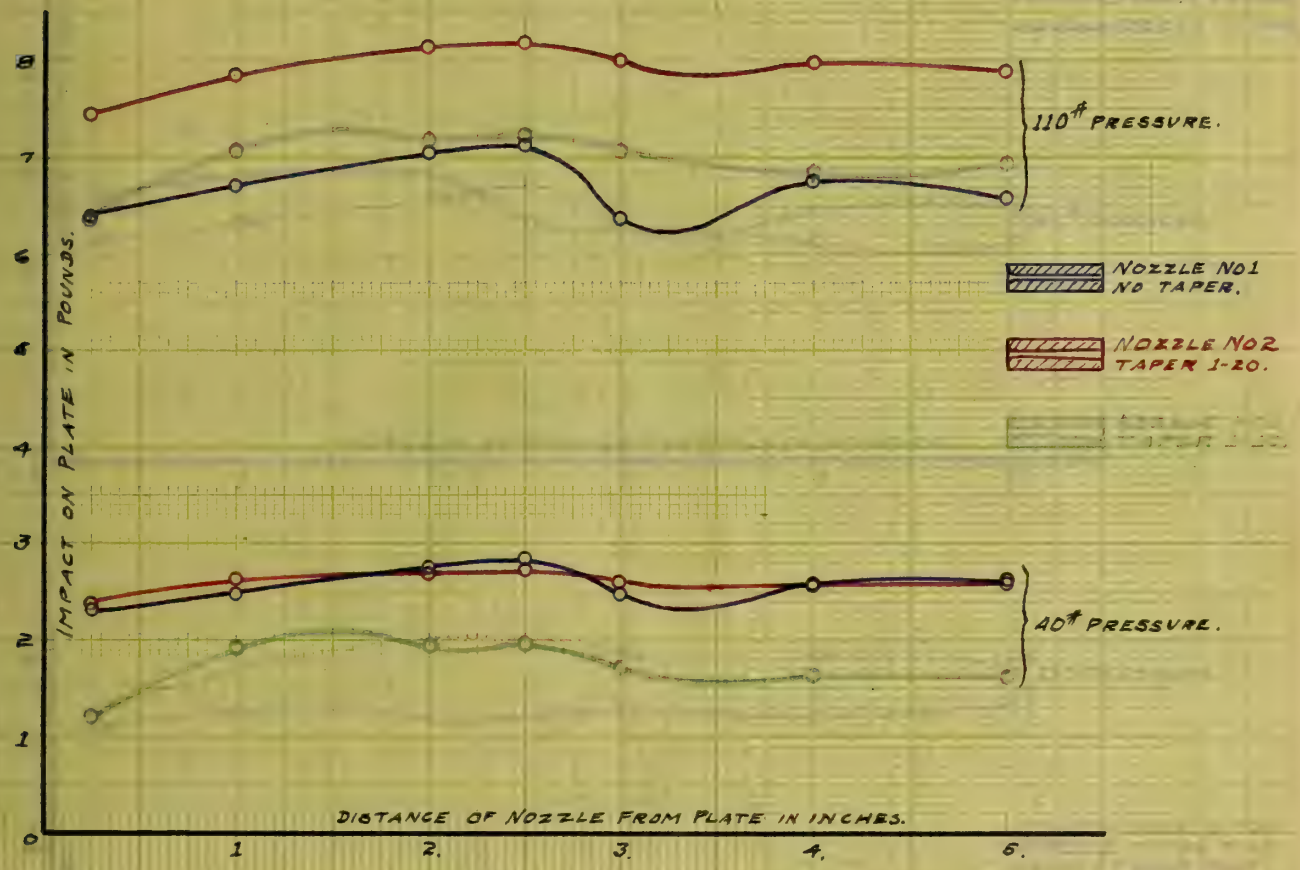


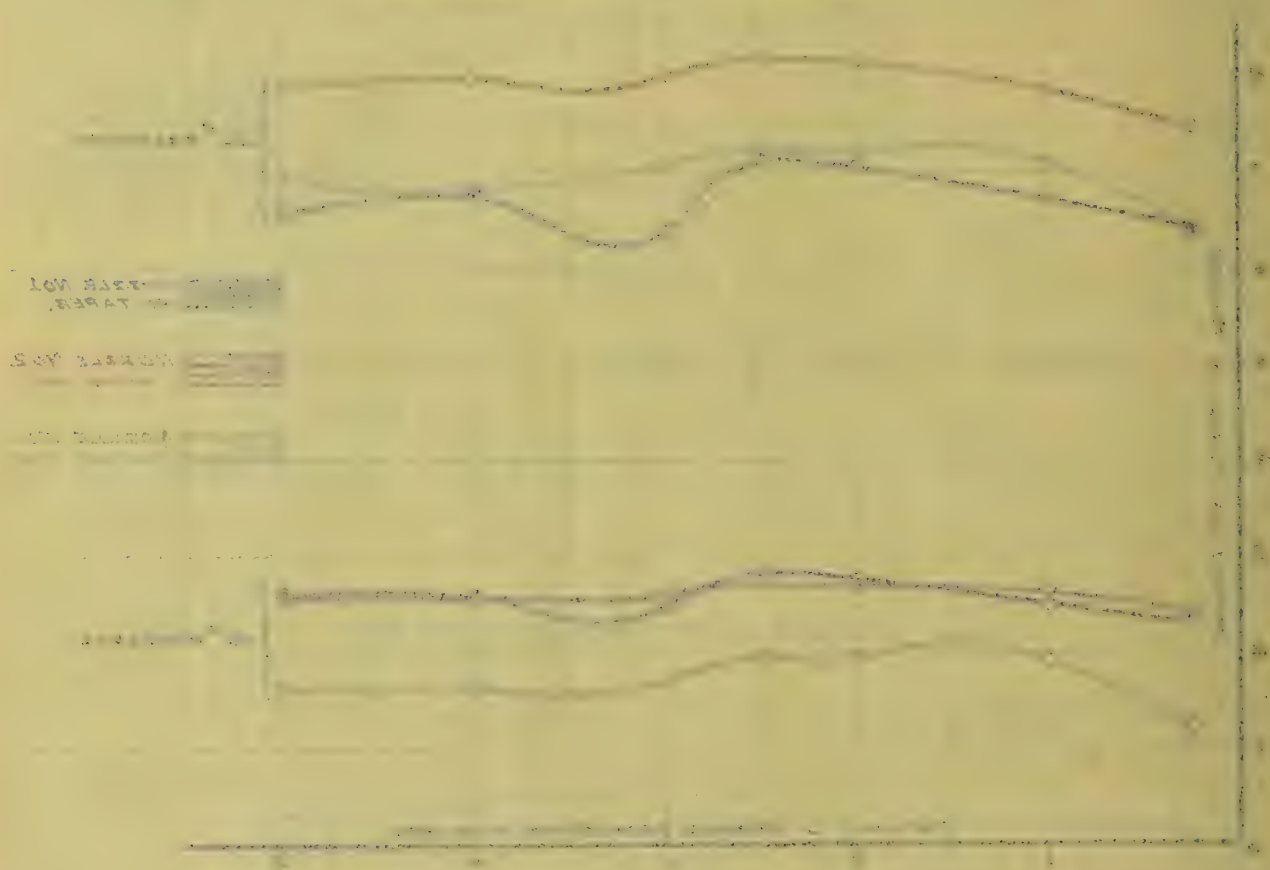
IMPACT CURVES.

SHOWING HOW IMPACT VARIES WITH NOZZLE DISTANCE.

LENGTH OF NOZZLE = $3\frac{1}{2}$".

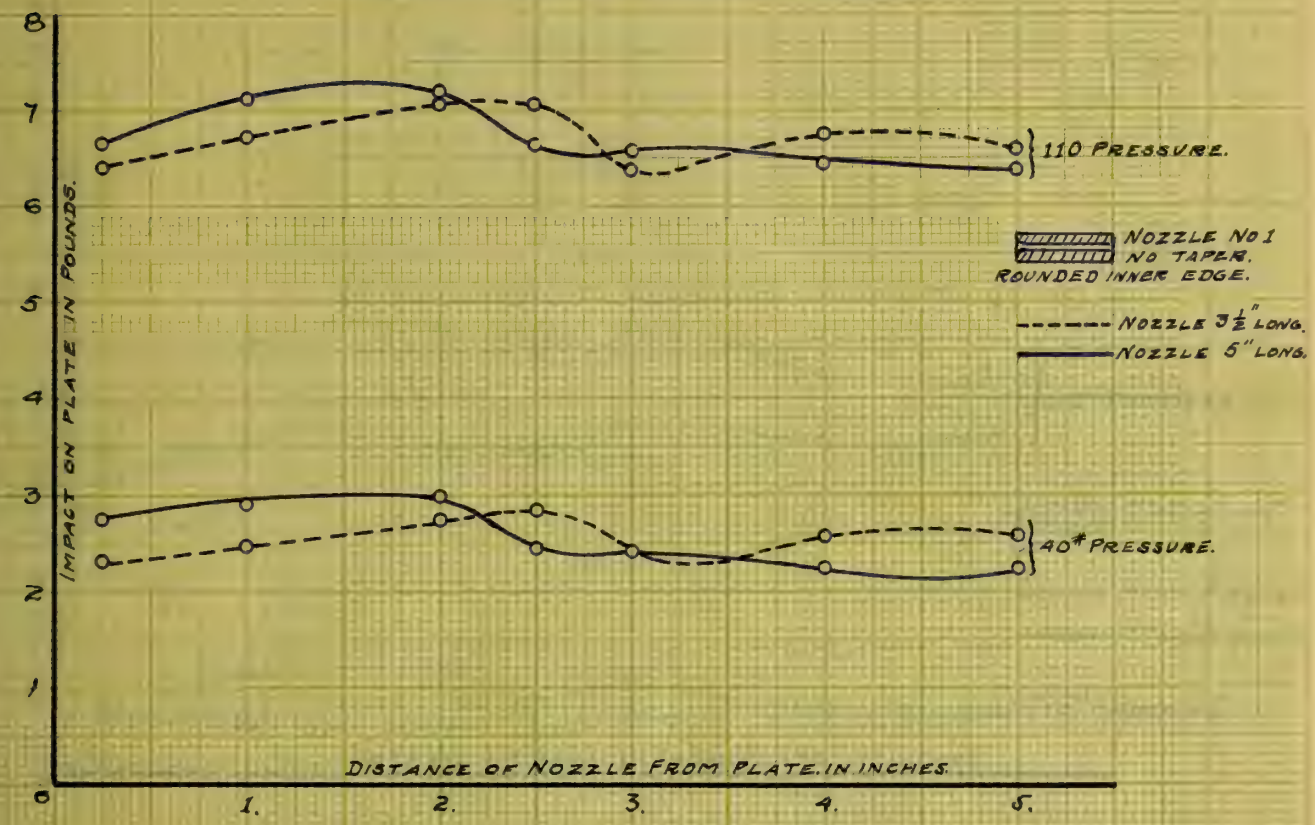
NOZZLES HAVING ROUNDED INNER EDGE.

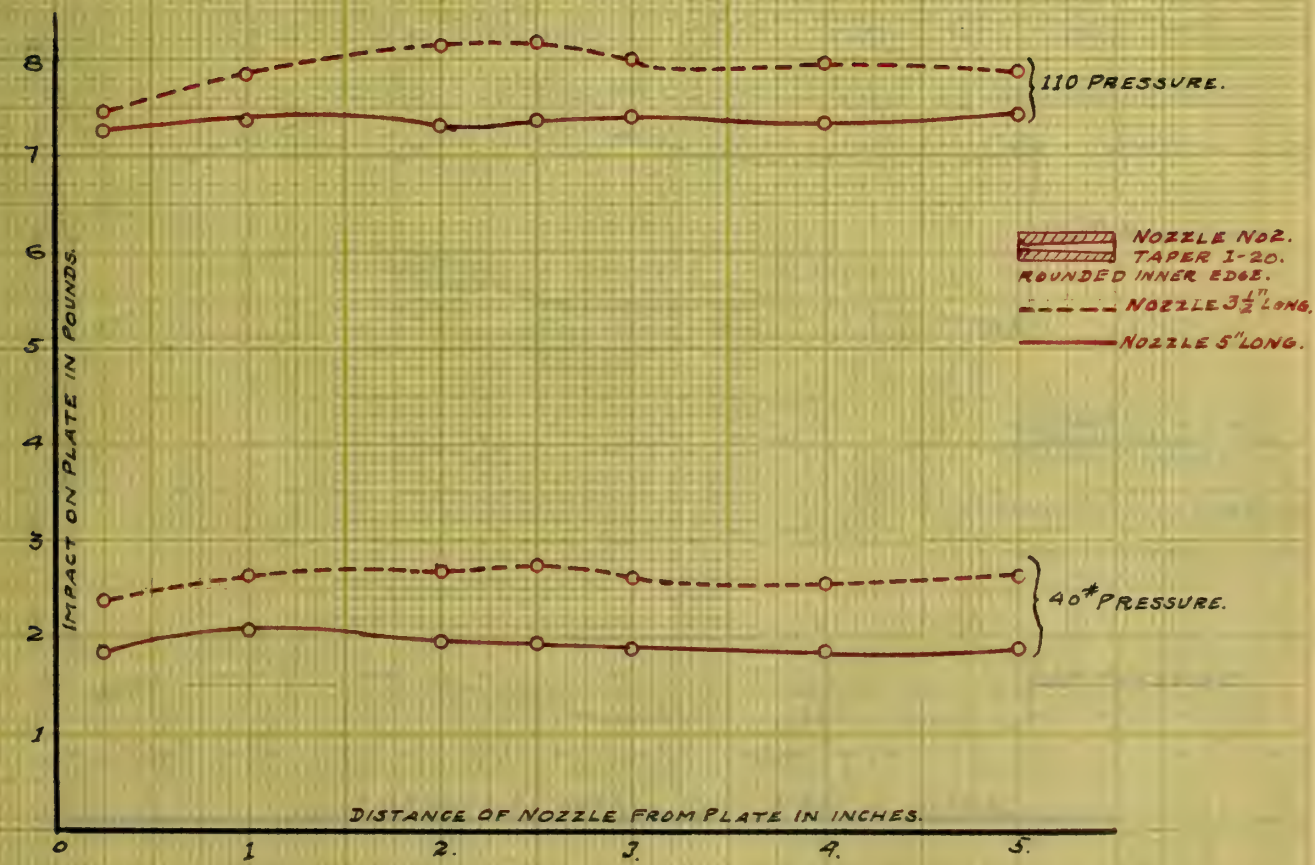


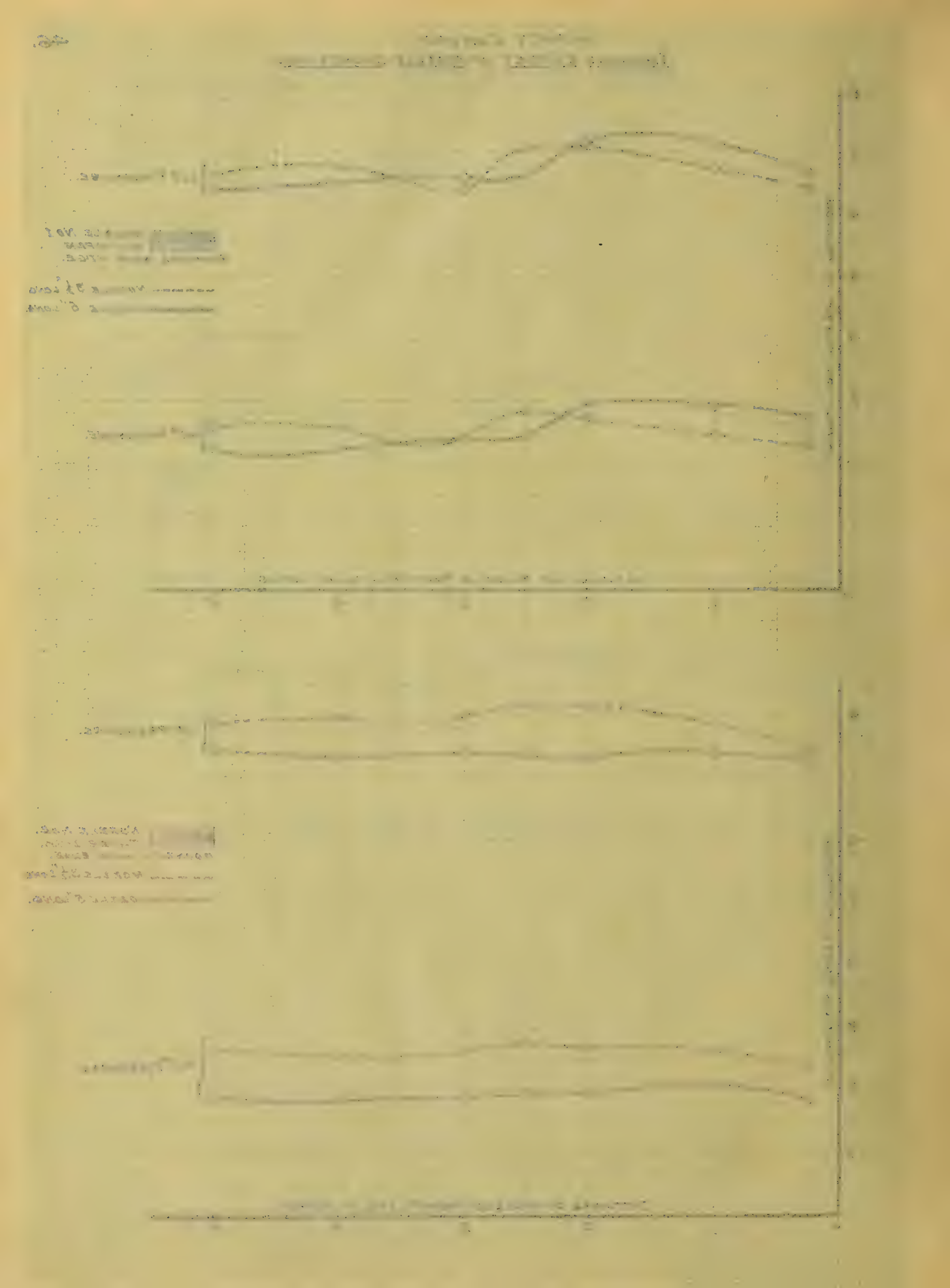


IMPACT CURVES.

SHOWING EFFECT OF NOZZLE SHORTENING.







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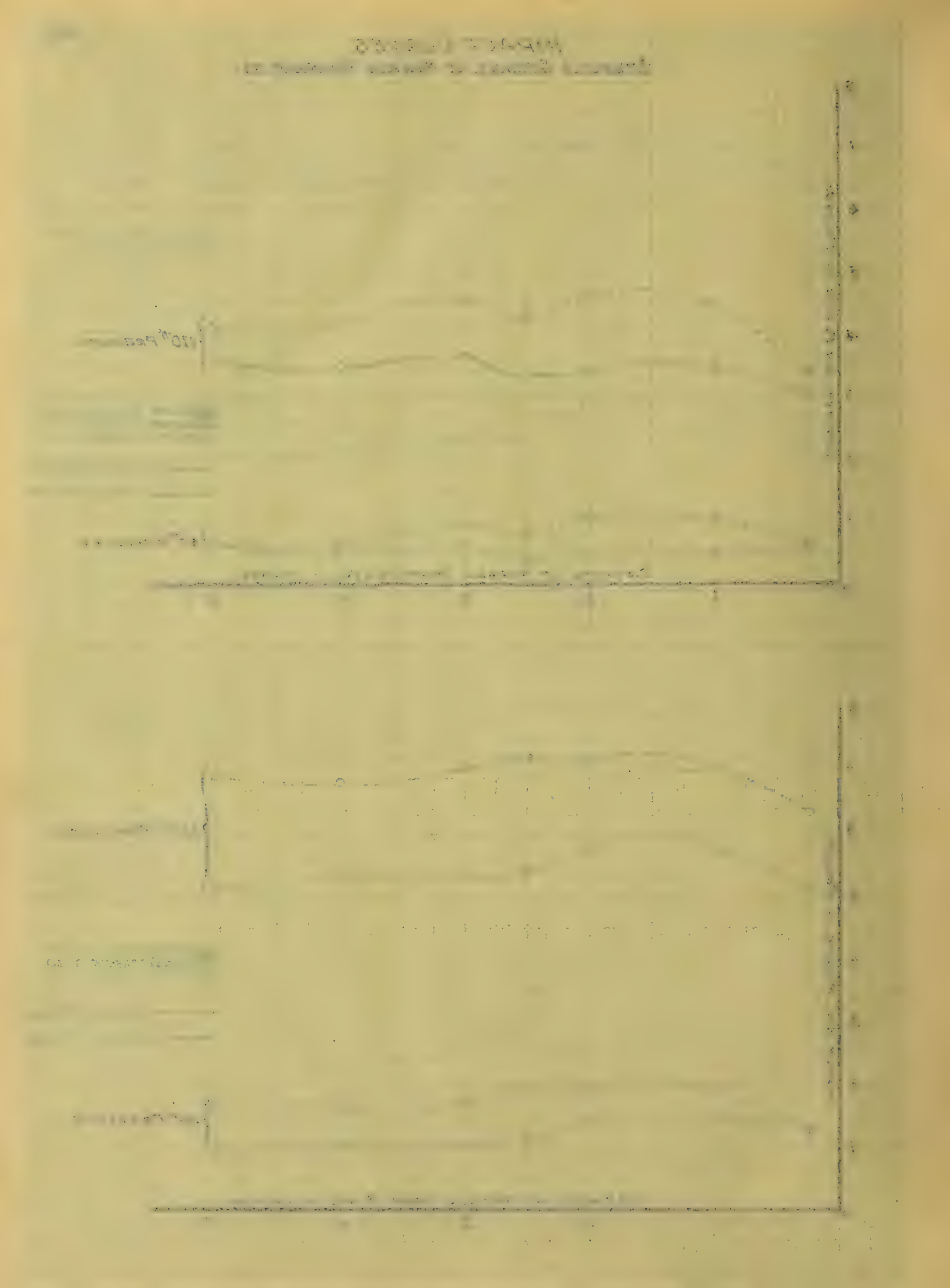

Conclusions.

Chapter V.

The first thing noticable in the impact curves is the wavy path of the point. This conforms to Stodola's results, and seems to follow out the theory that the pressure of the steam issuing from the nozzle follows a sort of sinusoidal curve, and the maximum and minimum impact is to be found on these points of the curve of exit of the steam.

The primary object of this thesis was to determine what effect the taper, the inner edge, and the length of a nozzle had on the impact of the issuing jet of steam. These points will be taken up under the following subheads.

Effect of the taper.

From a study of the pressure impact curves on page 41, it is seen that for a square inner edge the straight bore nozzle is the most advantageous, the taper of 1-30 next and lastly that of 1-10. These results are also shown in the impact curves on page 44. It seems that for lower pressures the difference of the two taper nozzles is not as great as for the higher pressures. So for a square inner edge the straight nozzle is to be preferred.

Effect of Rounding Inner Edge.

Some interesting facts are brought out by a study of the pressure impact curve on page 41, showing the effect of rounding the inner edge of the nozzles. The first effect is the increased impact resulting from this operation, this increase being less in the straight nozzle than the others, and more so in the latter as the pressure increases. From the curves it can be concluded that for pressures above 75# the taper of 1-20 is the most advantageous, that is compared with the straight nozzle. Following the curves further than shown, it appears that the taper of 1-10 would exceed the impact of the straight at pressures over about 130#. So it can be concluded that the working pressure of the nozzle should determine its taper, and that higher pressures need greater taper nozzles for the maximum impact.

The loss of impact of the taper nozzles at the lower pressures is probably due to expansion taking place too early in the nozzle, and then to such an extent as to take up energy available for impact, in whirlings within the nozzle. For the higher pressures this drop in energy is not so great, and hence the greater increase in impact.

Effect of Shortening the Nozzles.

The pressure impact curves on page 46 show the effect of nozzle shortening. It will be noticed that the impact is increased for each nozzle, and these proportionally equally at all pressures. The interesting fact that the taper nozzles permit greater impacts than the straight nozzle for lower pressures than with longer nozzle lengths is here plainly shown. Where for a 5" length the taper of 1-20 was more advantageous than the straight nozzle at pressures above 75#, it is now so at pressures above 40# with a 3½" length. The critical point of the 1-10 taper also drops from approximately 130# to 95#. It would be interesting to know the effect of further reducing the length, but in absence of further data, it can be concluded that the shortening of the nozzle increases the impact for all tapers, and in a less amount for a straight bore.

From the impact curves on page 46 it is seen that for a straight nozzle the mean curves are very close together, while for the taper of 1-20 they are further apart, and finally that the greatest increase is for the taper of 1-10.

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